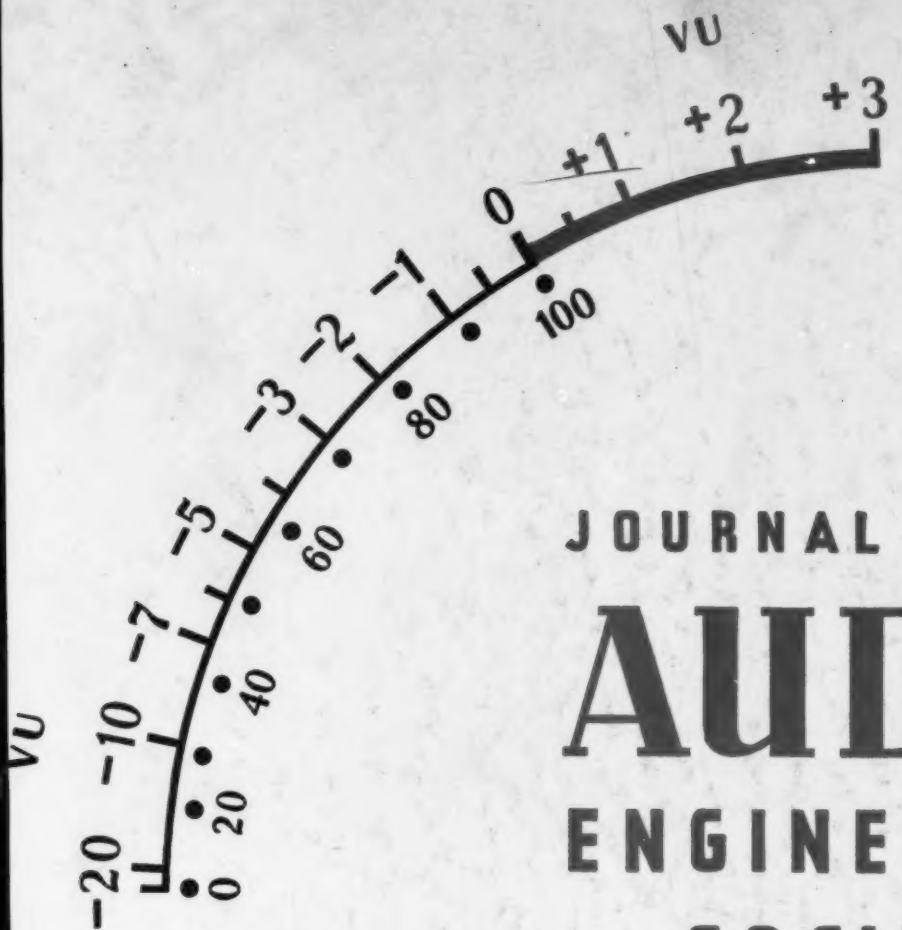

JOURNAL OF THE AUDIO ENGINEERING SOCIETY

COMING

Eighth Annual AES
East Coast Convention

VOLUME 3 NUMBER 4 OCTOBER 1955

Convention Program Committee Urges Prospective Authors To Submit Author's Forms and Manuscripts Immediately

The Eighth Annual East Coast Convention of the Audio Engineering Society will take place in New York City during the Fall of 1956.

The engineering papers to be presented will cover a wide range of subjects in audio and closely related fields.

THE GOALS: CUT TIME LAG, GET MAXIMUM PUBLICITY

One of the goals of the Audio Engineering Society is to cut down the time lag between presentation of papers and appearance in the JOURNAL of papers accepted for publication.

Another goal of the AES is to secure maximum national and local publicity—in regular newspapers, in scientific and technical journals, and in the trade press—for the AES Convention, for the papers to be presented and for their authors personally.

In order to help the AES achieve these goals in connection with the coming Fall Convention, persons desiring to submit papers on audio or on any related, pertinent subjects, will please do the following:

(1) Communicate your intention to submit a paper (along with an abstract of your proposed paper) as quickly as possible to the Chairman of the Convention Program Committee.

Several copies of the Audio Engineering Society's Author's Form will be mailed to you immediately.

(2) Prepare your manuscript—even if it is only a preliminary version—as quickly as possible.

WHERE TO SEND THE CARBON

The first carbon—a good, clean carbon—should be mailed to the Chairman, Convention Program Committee. *Purpose*: To permit final scheduling of your paper and to allow publicity work to begin.

Walter O. Stanton, Convention Program Chairman, may be addressed c/o Pickering & Company, Inc., Oceanside, N. Y.

WHERE TO SEND THE ORIGINAL

The *original* of the manuscript—i.e., the *ribbon* copy (plus all photographs, diagrams, charts, graphs and other illustrative materials)—should be mailed to the Editor of the JOURNAL OF THE AES. *Purpose*: To enable the Editor to start the manuscript moving through the regular reviewing and preparation channels without delay, in *advance* of the Convention proper.

Julius Postal, Editor of the JOURNAL OF THE AES, may be addressed at P. O. Box 49, Bowling Green Station, New York 4, N. Y.

A number of suggestions for prospective authors will be found on the inside rear cover page of the JOURNAL.

JOURNAL to Expand News Coverage, Publish Newsletter; Sections Requested to Designate News Representatives

In addition to the JOURNAL, members of the Audio Engineering Society will shortly begin to receive a small, printed newsletter. Inauguration of the newsletter will go hand in hand with greatly expanded coverage of AES news in the "Back of the Book" of the JOURNAL proper.

The aim is to knit our various sections and our far-flung membership more closely together—in friendship as well as in community of scientific and technical interests.

Frankly, we in audio are one of the most varied assemblages of people in the world.

Some of us design amplifiers. Some of us are physicists working in ferromagnetism or chemists expert in lacquers and record processing.

Other audio people are musicians and/or music lovers trying to make electro-mechanical systems duplicate what we hear in the concert hall.

Not a few of us are busy analyzing speech and tearing it apart, while others are just as busy synthesizing it and putting it together.

In our midst, too, are salesmen bridging the gap between the laboratory and the factory, on the one hand, and the consumer in the home or in industry, on the other.

Some of us are ornithologists recording the songs of birds in the field, or mammalogists lying in the bottoms of rowboats to record the sounds of whales in the sea.

Some of us are clergymen interested in sound-reinforcing systems.

Many of us build pipe organs while others experiment with the electronic variety.

Then there are the "old-timers" whose professional lives practically coincide with the origin and rise of the electronic art. Others are newcomers only lately arrived on the scene, but just as eager, just as intense, just as inquisitive.

All told, we in audio have a lot to say to each other. The AES newsletter should help us say it.

Will every section please designate someone to feed news to the Editor regularly? Certainly no section meeting, talk, lecture, demonstration or guided tour of a plant, recording studio, or motion-picture installation should go unreported.

Whenever possible, please send photographs of your audiences, your officers, your members. Tape recordings of your meetings will be helpful, too (*any* speed). The tapes will be mailed back to you, if you request it.

If you go on a business trip or visit a foreign country, we would like to hear about anything you see that has a bearing on audio.

We are eager, also, to hear from AES members in Canada, Europe, Asia, Africa, and South America.

If you are a lone member of the AES, located far from any convenient section, and you hear of any audio news that will interest the rest of our members, let's have it.

Please do not let considerations of style or form delay you: we are interested primarily in *facts*. Make sure, of course that names, addresses, dates, and companies or academic affiliations are given accurately.

Please address your news, photos, and tape recordings to the Editor as follows:

Julius Postal
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Journal of the
AUDIO ENGINEERING SOCIETY

VOLUME 3 NUMBER 4

OCTOBER 1955

Fundamentals of Speech Synthesis*

HOMER DUDLEY
Bell Telephone Laboratories, Incorporated, Murray Hill, New Jersey

From the communications engineer's point of view, there are two fundamental principles of human speech synthesis. The first is that speech is a message, which, in its initial expression from the body, is represented by a group of muscular vibrations—a multiplicity of telegraph signals functionally similar to the muscular vibrations of the finger in keying the simplest type of telegraph *on-off* signals. The second principle is that these "multiple telegraph signals" are made audible to the ear by modulating a set of carrier-frequency components in the audible part of the spectrum. Such components range from an inflected, buzz-like tone for voiced sounds to a hiss-like noise for unvoiced sounds, including whispers. The Vocoder was an early development of apparatus exploiting both of these basic characteristics of speech—the telegraph nature in the analyzer and the carrier nature in the synthesizer. If advantage is taken of the telegraph nature of speech, a large reduction can be effected in the frequency band required for transmission. Where long, expensive lines are concerned, economic benefit to the telephone user may accrue from such a reduction in bandwidth.

The ultimate in thus telegraphizing speech for transmission would be obtained in a system able to recognize phonetic elements and then transmit them by narrowband telegraph methods. Rudimentary experiments along these lines have been performed, using "Audrey," the automatic digit recognizer, to recognize the individual phonetic units at the *sending* end, and using a Vocoder at the *receiving* end for the purpose of synthesizing somewhat standardized speech from the telegraph-like currents transmitted from the sending end.

Other basic speech analyzer-synthesizer devices experimented with at the Bell Telephone Laboratories over the years are briefly reviewed; these devices include the Voder, the sound spectrograph, the visible-speech translator and synthesizer, the electrical vocal tract, and the improved Vocoder.

MAN AND HIS ancestors through the ages evolved for communication an amazing adaptation of the physiological parts furnished him by Nature[1] for purposes other than that of speech. Man expresses audibly an almost infinite variety of ideas by a three-stage process of selection: first, of words from a very large vocabulary; next, of sequences from a relatively small number of phonetic elements; and, finally, of motions of a few vocal parts serving as independent parameters. The overall process yields efficient and rapid communication. For clearer understanding, the simple case of speech production under control of a single parameter will be examined first.

* Presented at the Seventh Annual Convention of the Audio Engineering Society, New York, October 12–15, 1955.

[1] V. E. Negus, *The Comparative Anatomy and Physiology of the Larynx*, Appendices II and III, 192–209, Grune & Stratton, Inc., New York (1949).

THE TWO BASIC PRINCIPLES OF SPEECH SYNTHESIS

In Fig. 1 the interposition of a simple *on-off* telegraph circuit[2] segregates the points of application of the two fundamental principles of speech synthesis. The basic *telegraph* nature of speech is illustrated at the left of the figure as the communicator expresses his message by his finger motions onto a telegraph key to set up electrical waves corresponding to his finger motions. Similarly, the basic *carrier* nature[3] of speech is illustrated at the right of Fig. 1 where the inaudible finger motions are revealed by energizing the buzzer.

The basic advantage and disadvantage of the one-parameter telegraph type of speech communication are readily visualized from Fig. 1. The disadvantage is the slowness of the method. The key conditions of *on* and *off* correspond to a two-letter, or binary, alphabet. To transmit with an alphabet of 26 letters plus a blank requires 5 bits of information and therefore 5 time intervals per letter, as well as a correspondingly slower rate of speech synthesis than is the case in talking. Thus, 40 words per minute is fast for fingered-key telegraph, but 200 is common in talking. The basic advantage of fingered-key telegraph is that the connecting line, however long, need only transmit about 10 cps, in contrast with the audible speech band of 5000 cps or so—an enormous frequency-band reduction offering possibilities of developing economic savings to the telephone subscriber in situations where long, costly circuits are involved.

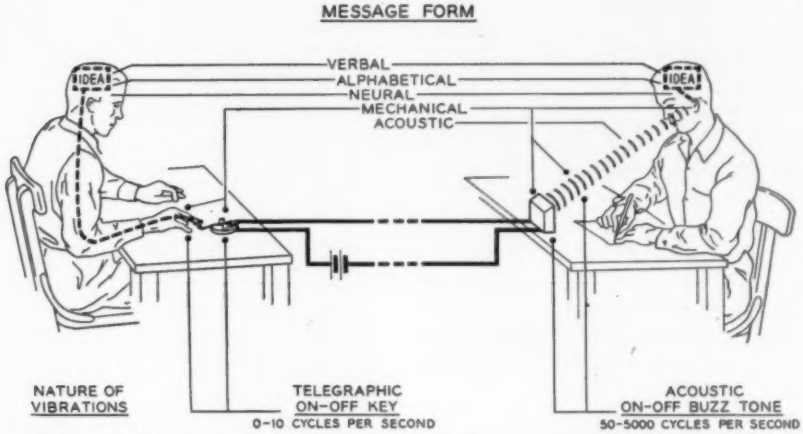

FIG. 1. One-parameter speech synthesizer with key-and-buzzer communication. Because time intervals are used for the coding of the 26 letters of the alphabet, the rate of word production is slow. (For a two-letter alphabet there would be no time penalty.) The coding may be that of Continental Morse or any other telegraph. The essential features are low-frequency telegraph motion of the finger and modulation onto an audible carrier.

Finally, Fig. 1 points up the complexity of speech communication by indicating that at least five message forms are involved in speech synthesis:

1. The verbal form, as the communicator puts into words the idea he desires to express. This will probably follow some initiatory stimulus; there may also be some thinking based on a set of symbols other than words.

2. The alphabetic form, as the letters are lined up for the words to be *spelled out*, or the phonemic form as phonemes are lined up for words to be *spoken*.

[2] In oversimplification we sometimes think of telegraph as restricted to the one-parameter, two-level, *on-off* fingered telegraph. Such telegraph finds only limited commercial use today. Our interest here lies in the displacements of body parts initiating the message. Thus, in the widely used teletype, simplified a bit, the operator fingers a keyboard with three parameter displacements to locate the chosen character: 11 keys for the X-displacement, 3 rows for the Y-displacement, and 2 levels for the Z-displacement. Furthermore, some telegraph parameters cover a continuous range, as in the commonly used two-parameter telautograph, defined by Webster as "a facsimile telegraph for reproducing writing, pictures, maps, etc." The basic difference, etymologically, between telegraph and telephone is that the former deals with graphic material, the latter with phonic. It is in this broad sense in the field of speech material that the word telegraph is used in this paper. The telegraph concept stresses the three basic common features in speech production and fingered telegraph: communication by words, initial expression by body displacements, and use of the same subaudible frequency range. This concept also stresses the point that the basic difference of the past, i.e., that of audible versus visible material, is losing much of its significance as new circuits are developed to print the spoken word automatically and also to speak the printed word. Such circuits not only lead to automatic conversion from the spoken to the written word, and vice versa, but also yield methods of control by either.

[3] H. Dudley, "The Carrier Nature of Speech," *Bell System Technical J.*, **19**, 495–515 (October 1940).

3. The neural form, as all-or-none, spike-like electrical pulses are transmitted over routing nerves.

4. The mechanical form, as body parts are displaced with subaudible motions.

5. Finally, the acoustic form, as audible carrier waves are modulated to carry the imprint of the message in a form which the observer's ear can perceive.

In the listener these five message forms appear in reverse order. These 5 message forms present the message in 5 different codes. A message, in coding, passes to a different form but may be restored by reverse coding. Codes are commonly used for secrecy, as in military communications, and for brevity with cost reduction, as in transmission by telegraph over submarine cable with Bentley's code. In Fig. 1, the message form coding is for operability in the medium concerned, the reason that applies to the use of Continental or other code in telegraph characters. These coding aspects stress again the telegraph nature of speech.

The external electromechanical apparatus in Fig. 1 is not essential to one-parameter speech communication, for generous Nature has provided man with adequate self-contained apparatus for this purpose. Normally, man does not use such a method of speech synthesis, for, after all, he has evolved and mastered a more complicated but much speedier method—one therefore far superior for his communication purposes.

However, the two basic principles of the telegraph nature of speech and the carrier nature of speech are also readily observable in man's simplified communication system, illustrated in Fig. 2. Here is represented *on-off* voicing communication, with the vocal cord tone replacing the buzzer tone of Fig. 1 and with the lips taking the place of the ON-OFF switch, the nasal passage being cut off at the uvula. The communicator then codes his vocal-cord tone into voiced telegraph, spelling out the letters in Continental, Morse code or another code.

Man can form such a binary voice telegraph in many other ways. Thus, he can start and stop his cord tone by turning on and off the air stream from the lungs. This is equivalent to switching the battery on and off in Fig. 1. Similarly, from 39 or so sustainable speech sounds—including 11 whispered vowels—he can select any one of these sounds to correspond to the *"on"* condition and any other sound for the *"off"* condition; over a thousand such combinations are available.

THE HUMAN SPEECH SYNTHESIZER

The savage in the forest may be content with his drum beating out a one-parameter message, but, in the *general* case, man synthesizes his speech message by controlling the simultaneous variations of a multiplicity of independent parameters, as represented in Fig. 3. The basic principles of the telegraph nature and the carrier nature of speech still hold, but now speedy, multiparameter telegraph appears, instead of the slowed-up single-parameter telegraph of sequential time intervals indicated in Figs. 1 and 2.

There is a very simple method for visualizing the telegraph nature of the various speech parameters found in the muscular stage of speech production. Imagine a man going through all the motions of talking except that he holds his breath to eliminate the carrier tone (whether it is of the buzz type or hiss type). In this case, the telegraph motions are all present, but no audible sound is heard, for there is now no carrier modulation of the subaudible telegraph signals into the audible frequency range. These telegraph wave motions offer the lip reader his only means of speech recognition, but even the lip reader would need X-ray vision to see enough of the moving parts to permit a complete and

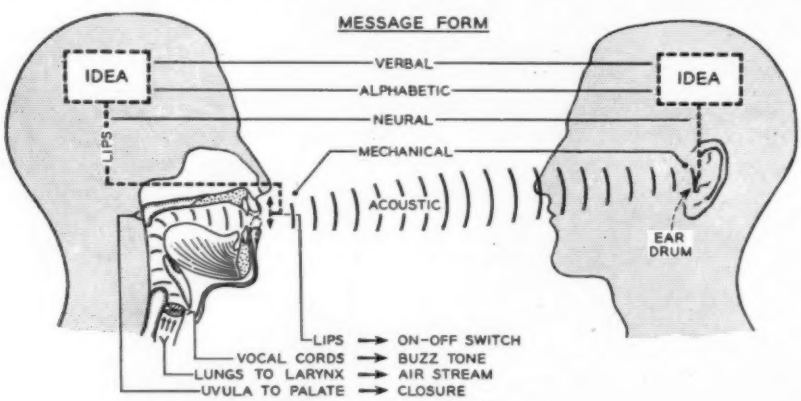

FIG. 2. One-parameter speech synthesizer with *on-off* voicing communication. The essential features are low-frequency telegraph motion of the lips with modulation onto the audible carrier furnished by the vocal cords. The communication elements are analogous to those in Fig. 1, but are self-contained vocal parts instead of non-vocal parts.

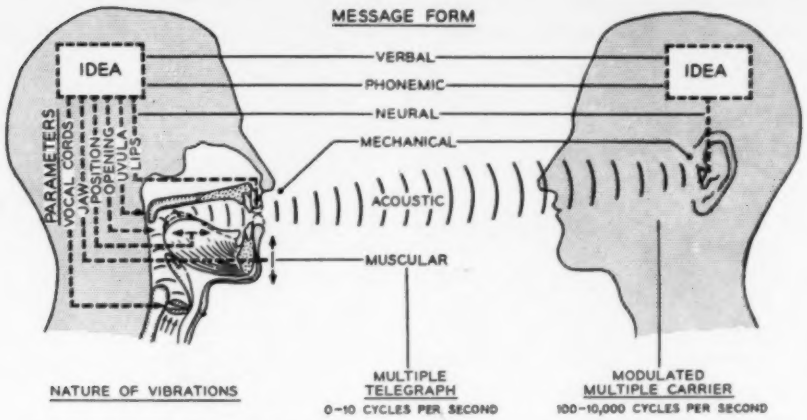

FIG. 3. Six-parameter speech synthesizer with spoken communication. Again an audible carrier is modulated at telegraph rates, but this time a multiplicity of parameters is used. This affords sufficient combinations for the speech sounds so that the communication is speeded up by obviating the need for a multiplicity of time intervals to yield the combinations for time-coded sounds.

therefore accurate interpretation of speech on the basis of the telegraph wave motions alone. The fact that the tongue, uvula, etc. are concealed is what makes lip reading so difficult and uncertain for the person who uses it. To such a person, lip-reading is, at best, a sort of crutch, for he sees only *1* parameter in speech that is effectively *6*-fingered telegraph.

The parameters shown in Fig. 3 for normal speech synthesis are six in number,[4] namely:

1. Vocal-cord positioning through the arytenoid cartilage-muscle structure.
2. Lower jaw position.
3. Tongue hump position.
4. Opening between tongue hump and palate.
5. Uvula position.
6. Opening between lips.

[4] This enumeration is somewhat arbitrary. A ventriloquist produces very good speech without moving the lower jaw, so that parameter no. 2 may be superfluous. On the other hand, while the ventriloquist is forced, for professional reasons, to keep a relatively fixed lip position also, he does this with considerable difficulty in articulating sounds like *p*, *b*, and *m* by some substitute method, such as the use of the tongue tip, so that the mouth opening seems to be definitely a required parameter. The exact number of independent parameters, whether six or some other number, is not of great significance for our understanding of the underlying principles. The very fact that a limited number of alphabetic or phonetic characters are used for the written and spoken words, respectively, indicates that a single parameter might control a number of parametric positions, thus, in effect, reducing the number of parameters to limits set by other engineering features in speech-synthesizing apparatus.

A normal or natural talking level is assumed. Parameter no. 1, the vocal-cord positioning, varies over a continuous range, with corresponding pitch change, although the contribution made by pitch to information content is small. Parameter no. 5, the uvula position, takes on one of two values—wide open or completely closed to the back of the pharynx. While the other four parameters can vary continuously, in practice a limited number of discrete values give the best approximations to the desired sounds. In the flow of speech there is a "rounding of corners," so to speak, with corresponding phonetic variation, whereas in telegraph, *discrete* letters are printed distinctly without any rounding out. The "corner rounding" in speech helps to make the fast talking rates possible.

As the aforementioned parameters contain the speech specifications with little of the redundancy found in the great multiplicity of audible carrier frequencies occurring in direct speech, it is of interest to apply information theory[5] as a guide in transmission applications. Thus, by information theory, when signal and noise amplitudes are distributed with respect to time in accordance with a Gaussian normal-error law,

$$C = W \log_2 \frac{S+N}{N} \qquad (1)$$

where C is the channel capacity in number of bits of infor-

[5] C. E. Shannon, "A Mathematical Theory of Communication," *Bell System Technical J.*, **27**, 379-423 (July 1948) and 623-656 (October 1948).

mation transmittable per second with arbitrarily small equivocation, W is the required bandwidth in cycles per second, S is the average signal power, and N is the average noise power. One physical interpretation of this formula is that if a certain frequency band is required to transmit information on a two-level or binary basis, then the same frequency band is all that is required to transmit correspondingly *more* information by the use of a greater number of levels, provided that the signal is maintained at a correspondingly higher value relative to a given noise than is required for the two-level case.

APPLICATIONS

Briefly reviewed next will be a number of applications developed at the Bell Telephone Laboratories in line with the fundamentals of speech analysis-synthesis as discussed above. The criterion applied to any apparatus will be whether its presentation, aural or visual, makes use of the telegraph nature of speech. In this connection it is instructive to scrutinize a high-quality oscillogram of speech, as in Fig. 4, made in connection with Crandall's speech studies.[6] Here the sluggish speech changes correspond to the motions of the various parts of the vocal system, occurring at telegraph rates. The exception to the sluggish change is in the sound carrier, which appears in the form of a buzz-like tone generated by the vocal cords, and in the hiss-like noise generated by turbulence formed at narrow constrictions in the vocal tract. One notes the gradual shift in the shape of the first large pulse in each vocal period and can follow the *gradual* change through *many* periods. However, since the oscillogram presents all the high-frequency carrier detail of the speech, it is not considered to involve the basic principles of speech analysis and synthesis discussed here.

In the several pieces of apparatus to be reviewed briefly, low-frequency, telegraph-like patterns will be clearly revealed. The carrier components are actually detected and at least partially removed in the analyzing process, although they will, of course, be restored in some degree of similitude when the analysis is followed by a correlated synthesis.

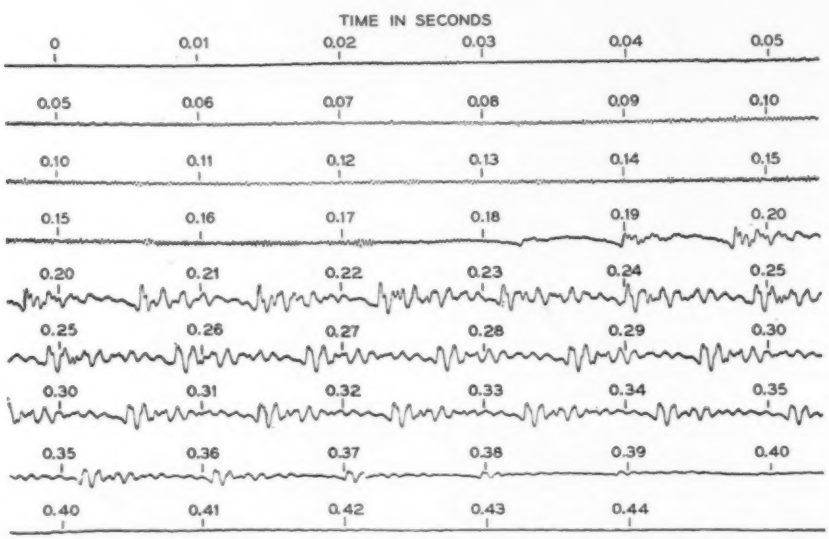

FIG. 4. High-quality oscillogram for the syllable *sa* spoken by a low-pitched male voice. One can readily observe the telegraph rates of change impressed on the voiced and unvoiced carriers.

THE VOCODER

The foregoing fundamentals of speech synthesis were exploited in the Vocoder (VOice CODER), first demonstrated at the Harvard Tercentenary in September 1936.[7] Speech is picked up by a microphone shown in the plan of Fig. 5 for analysis into a set of telegraph-like defining currents. Fig. 6 gives the circuit in block schematic form. The telegraph-

[6] I. B. Crandall, "The Sounds of Speech," *Bell System Technical J.*, 4, 586-626 (October 1925).

[7] H. Dudley, "Synthesizing Speech," *Bell Laboratories Record*, 15, 98-102 (December 1936); "Remaking Speech," *J. Acoust. Soc. Amer.*, 11, 169-177 (October 1939).

like signals constitute a set of currents prescribing the amount of power in a corresponding set of frequency bands covering the speech range, plus another current that is a measure of pitch, with a negligible value taken to indicate a degenerate pitch, i.e., the condition for a hiss-like energy source, as needed for the whispered and unvoiced sounds. Such a set of telegraph-like signals is shown in Fig. 7, along with the original spoken words "showing speech remade" and the remade speech after the external carrier tones, supplied at the synthesizer, are modulated by the transmitted telegraph-like message signals. Fig. 8 presents an early model of a demonstration Vocoder having 20 uniform-width frequency bands below 3000 cps, and 10 above, extending logarithmically from 3000 to 7500 cps.

At the Sound Creation session of the recent Audio Engineering Society Convention† a recorded demonstration of the Vocoder was given in which the buzz-hiss tone for simulating the vocal-cord breath energy was replaced by a magnetic recording of an instrumental selection. In effect, a

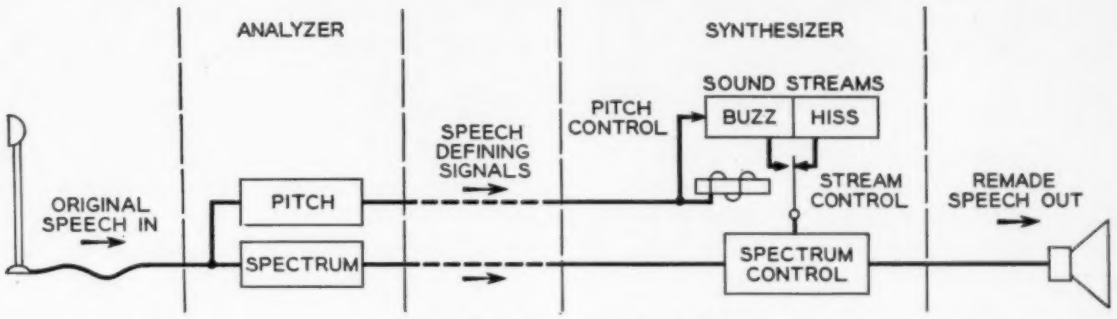

Fig. 5. Functional plan of the Vocoder.

† Seventh Annual Convention of the Audio Engineering Society, New York, October 12–15, 1955. This recorded demonstration accompanied Mr. Dudley's oral version of the present paper.

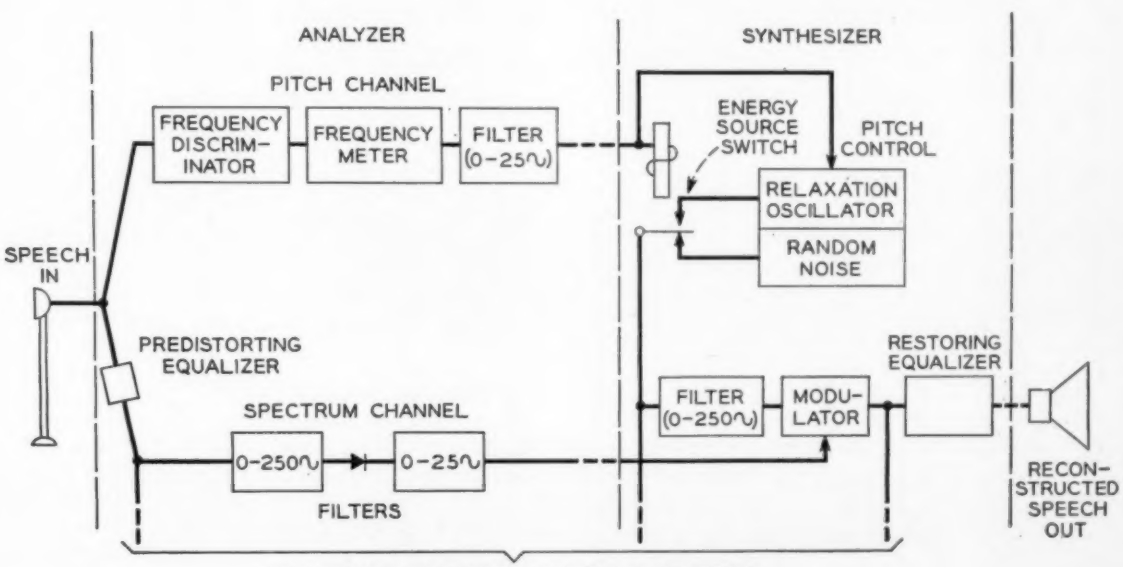

Fig. 6. Block schematic of the Vocoder circuit.

musical instrument was substituted for the vocal cords.

VODER

Another device developed which is based on the telegraph and carrier nature of speech is the Voder (or Voice Operation DEmonstratoR[8]) exhibited at the World's Fairs of New York and San Francisco in 1939-40, as illustrated in Fig. 9.

ELECTRICAL VOCAL TRACT

For the vowel sounds, far better quality has been obtained with the electrical vocal tract, pictured in Fig. 11, designed by H. K. Dunn.[9] In Fig. 12, at the top, is represented a cross section of the vocal tract with the various vocal parts positioned to produce the sound of *u* as in *rule*. Below, in the figure, is shown the electrical analogue built. A vibra-

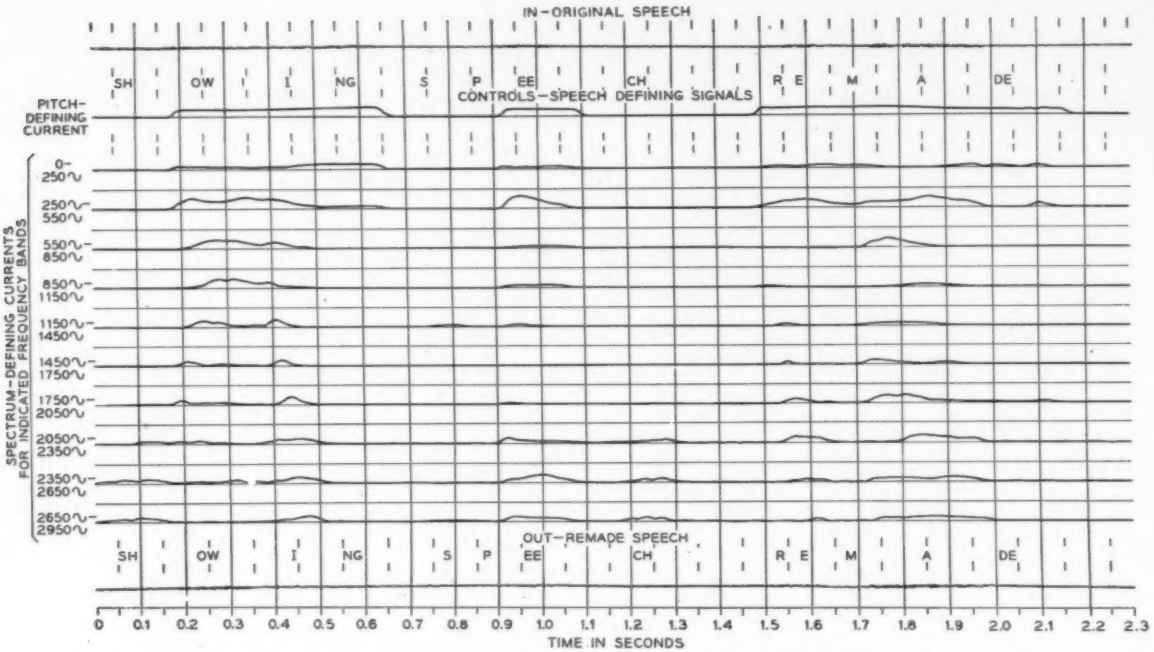
IN—ORIGINAL SPEECH
SH OW I NG S P EE CH R E M A DE
CONTROLS—SPEECH DEFINING SIGNALS
PITCH-DEFINING CURRENT
SPECTRUM-DEFINING CURRENTS FOR INDICATED FREQUENCY BANDS
0-250~
250~-550~
550~-850~
850~-1150~
1150~-1450~
1450~-1750~
1750~-2050~
2050~-2350~
2350~-2650~
2650~-2950~
OUT—REMADE SPEECH
SH OW I NG S P EE CH R E M A DE
0 0.1 0.2 0.3 0.4 0.5 0.6 0.7 0.8 0.9 1.0 1.1 1.2 1.3 1.4 1.5 1.6 1.7 1.8 1.9 2.0 2.1 2.2 2.3
TIME IN SECONDS

FIG. 7. Example of telegraph-like control currents of the Vocoder. The original speech analyzed and the speech synthesized are also shown.

The circuit features are represented in analogy in Fig. 10. A recording of synthesized speech from such a Voder was played at the aforementioned Sound Creation session of the AES. Apparent from the demonstration was the difficulty of forming intelligible speech sounds by this method, although a skillful, trained operator—giving cued responses to her interlocutor—could form speech and certain other sounds that would then be almost perfectly understood by all the listeners. Perhaps the wonder was that the Voder should talk at all.

The exhibits at the two World's Fairs centered about the nature of speech; special stress was laid on the components making up the speech sounds, as indicative of the material to be handled over telephone lines.

tory energy source replaces the vocal cords. For the vocal passage there is substituted an electrical line made of a number of low-pass filter sections: their purpose is to provide delay simulating the vocal-tract delay as the sound wave is passed along. For the tongue hump constriction, a coil is substituted which can be varied in inductance to accord with the opening. The location of the coil along the electrical line can also be varied to correspond to the location of the hump. At the end of the line, there is another coil which is varied in accordance with the lip opening. The sound formed then issues from a loudspeaker.

With this device the vowel gradations could be produced quite clearly, as was demonstrated at the Sound Creation session by means of a tape recording.

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[8] H. Dudley, R. R. Reisz, and S. S. A. Watkins, "A Synthetic Speaker," *J. Franklin Inst.*, **227**, 739-764 (June 1939).

[9] H. K. Dunn, "The Calculation of Vowel Resonances and an Electrical Vocal Tract," *J. Acoust. Soc. Amer.*, **22**, 740-753 (November 1950).

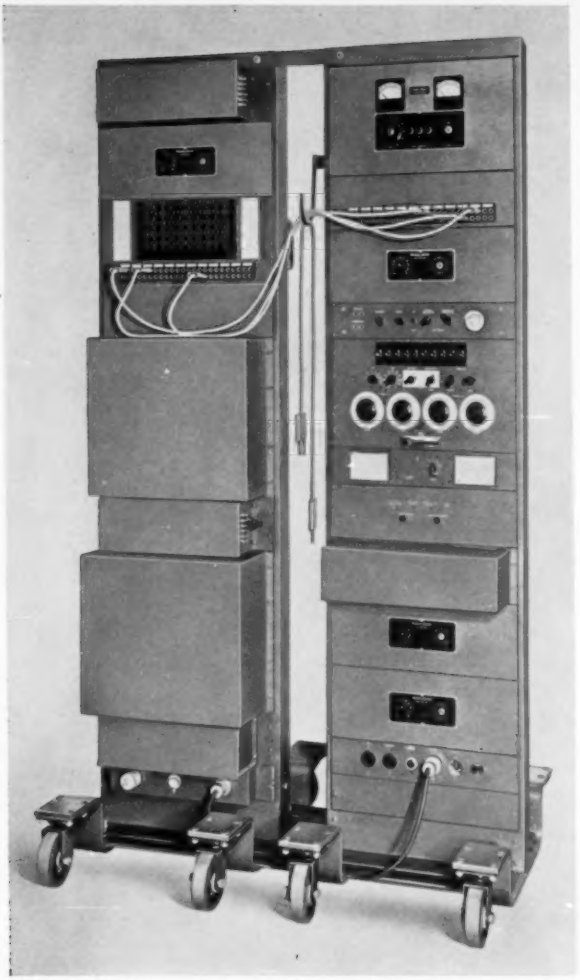


FIG. 8. Early form of a frequency-band type of demonstration Vocoder.

K. N. Stevens has furthered the development of the artificial vocal tract, as he also demonstrated at the Sound Creation session of the AES Convention.

SOUND SPECTROGRAPH

Another device developed, the sound spectrograph,[10] shown in Fig. 13, can display the telegraph-like character of speech for the eye to view without any carrier synthesis of speech for the ear to hear. As the speech display is for interpretation by the eyes, it has been termed "visible speech."[11]

[10] W. Koenig, H. K. Dunn, and L. Y. Lacy, "The Sound Spectrograph," *J. Acoust. Soc. Amer.*, 18, 19-49 (July 1946).

The basic principle of the sound spectrograph is shown in Fig. 14. The sample of speech to be analyzed is recorded on a loop of magnetic tape. This recording is then played back many times as an analyzing band filter—by heterodyne methods—advances through the speech band. The output of this filter energizes an advancing stylus which writes on electrosensitive paper mounted on a rotating drum. Thus, line by line, a spectrogram is produced, giving a three-dimensional display of energy versus frequency and time.

Such a spectrogram of speech is shown at the top of Fig. 15 for a 45-cps band analyzing filter and in the center for a 300-cps band. The bottom spectrogram gives a sectional, or two-dimensional, plot of power versus frequency at three indicated times.

To obtain the sectional display[12] the same sound spectro-

[11] R. K. Potter, G. A. Kopp, and H. C. Green, *Visible Speech*, D. Van Nostrand Co., Inc., New York, 1947. While most of this book is devoted to a discussion of visible speech and the principles underlying it, there is also a discussion of the apparatus used and of a few visible patterns of non-speech sounds.

[12] L. G. Kersta, "Amplitude Cross-Section Representation with the Sound Spectrograph," *J. Acoust. Soc. Amer.*, 20, 796–801 (November 1948).

FIG. 9. The Voder demonstration at the New York World's Fair (1939-40).

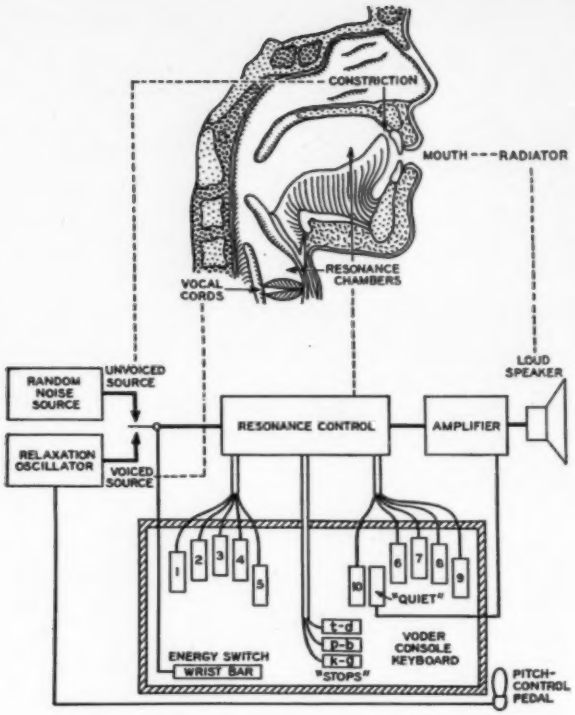


FIG. 10. The Voder analog.

graph is employed, but pins are placed on the drum corresponding to the times chosen for such analyses; the stylus circuit is left normally open, to be closed by a switch actuated by the pins as they rotate past. The sectional plot is for the narrowband analyzing filter, the wideband filter yielding a filled-in pattern.

A limiting feature of the spectrogram is its range of photometric density, somewhat less than 10 db under the best conditions. This defect is overcome in part by automatic volume compression and adjustment of the speech signal analyzed, but in large areas weaker level components are not seen. Also, the lines have a variable width, due to the fact that the filter is not infinitely sharp in its cutoff. Neither of these limitations is serious, particularly as adjustment can be made for them just as, in photography, focus adjustment is made for distance.

Typical speech information that can be revealed by sound spectrograph analysis is indicated in Figs. 16, 17, and 18. Various phonetic factors are marked on Fig. 16 for the spectrogram of the words *speech we may see*. The resonance bars marked correspond to formant frequencies. It has been found that the two bars of lowest frequency characterize fairly accurately the specific vowels. These have been plot-

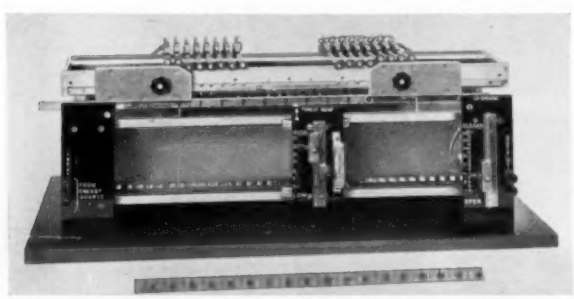
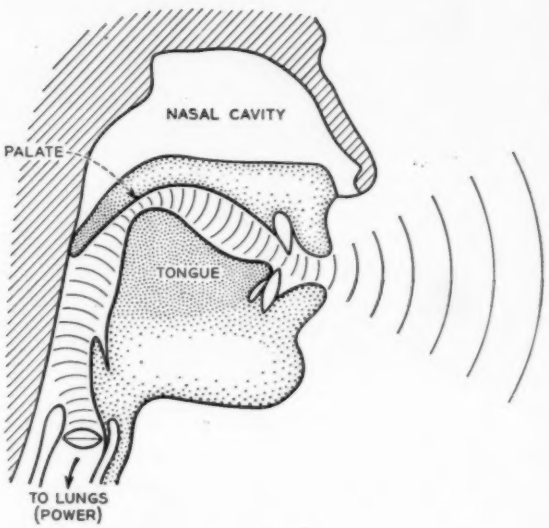


FIG. 11. Electrical vocal tract designed by H. K. Dunn.



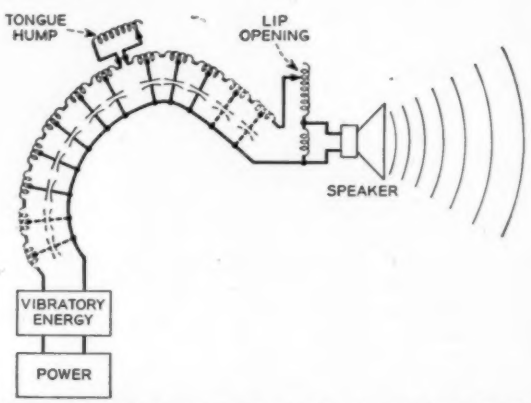


FIG. 12. Simulative schematic circuit of vocal tract forming sound *u*, as in *rule*.

ted[13] in Fig. 17 for the vowels spoken with a preceding *h* and a following *d*. The line connecting the plotted points forms a vowel loop which is found to resemble closely the vowel loop typically used by phoneticians plotting a tongue-hump position of front versus back, and low versus high, as indicated around the loop shown. For sounds in which energy change with time is as indicatory as—or *more* indicatory than—mean energy distribution, Kock[14] and Miller have modified the spectrograph circuit to display dynamic spectrograms, as illustrated in Fig. 18.

The sound spectrograph offers advantages in analyzing the performance of other apparatus used in speech analysis-synthesis. In Fig. 19 there are shown for comparison the spectrograms of the sustained vowels as *spoken* (below), and as made with Dunn's electrical vocal tract (above.) This spectrograph can be used for displaying any three-dimensional relations when the quantities can be expressed electrically, as they can generally be; the device therefore finds a field of use far broader than that of speech analysis alone. In particular, the spectrograph need not be limited to the speech-frequency range.

The display in the middle spectrogram of Fig. 15 is seen to be almost altogether of the telegraph nature of speech. The same is true in Fig. 16, except for the vertical striations which represent the first audible carrier of speech, the vocal-cord fundamental itself. These striations mask slightly the underlying speech telegraph patterns. However, in the top spectrogram of Fig. 15, the 45-cps filter separates out all the harmonic components of speech, so that the entire carrier pattern of the speech is displayed with the telegraph pattern only revealed by the generally deeper shading. One can bring out the telegraph pattern here fairly well by viewing the illustration at a glancing angle.

FIG. 13. Sound spectrograph.

[13] G. E. Peterson and H. L. Barney, "Control Methods Used in a Study of the Vowels," *J. Acoust. Soc. Amer.*, **24**, 175–184 (March 1952); G. E. Peterson, "The Phonetic Value of Vowels," *Language*, **27**, 541–553 (October-December 1951).

[14] W. E. Kock, "The Problem of Selective Voice Control," *J. Acoust. Soc. Amer.*, **24**, 625–628 (November 1952); W. E. Kock and R. L. Miller, "Dynamic Spectrograms of Speech," *ibid.*, 783–784.

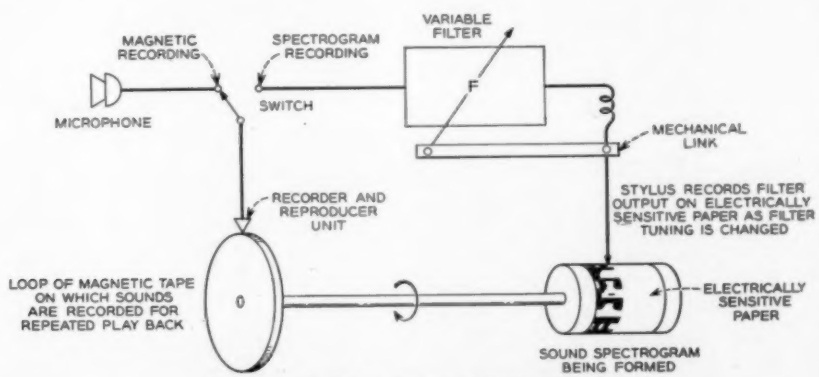


FIG. 14. Principle of the sound spectrograph.

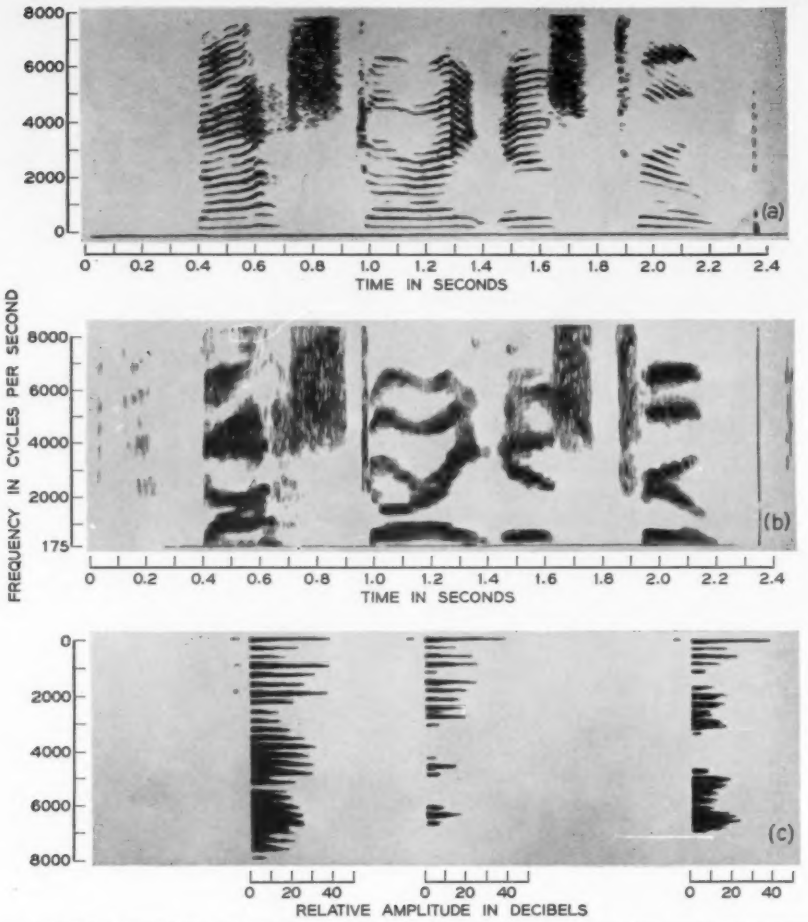


FIG. 15. Narrowband, wideband, and section spectrograms for the spoken words, *The story is true.*

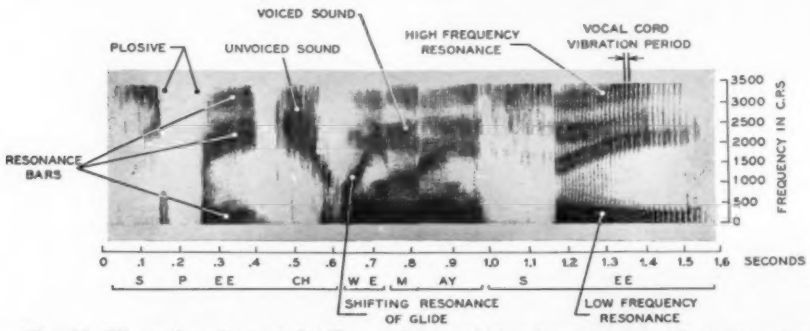


FIG. 16. Illustration of speech details revealed by wideband spectrogram. The information is chiefly of telegraph frequency, although the fundamental of the vocal-cord carrier is revealed by striation.

VISIBLE-SPEECH TRANSLATOR

Spectrographic speech in dynamic form has been displayed on moving phosphor belts by means of the circuit represented in Fig. 20.[15] The visible speech patterns thus displayed may be of value for reading by the deaf. In Fig. 21 is shown a small class studying the possibilities of such a translator with respect to the training needed to obtain functional recognizability.

VISIBLE-SPEECH SYNTHESIZER

The translator, with its patterns for the eye, is based on the telegraph nature of speech. However, one interesting attempt was made to apply the speech-carrier principle in setting up shadow patterns from which speech could be synthesized by photoelectric modulation. Pictured in Fig. 22 is the apparatus[16] demonstrated in 1951 at the centennial ceremonies commemorating Alexander Graham Bell's birth. Since this early work other laboratories have employed such playback systems with considerable success in phonetic analysis, as J. Borst of Haskins Laboratories brought out in his paper at the Sound Creation session of the AES Convention.‡

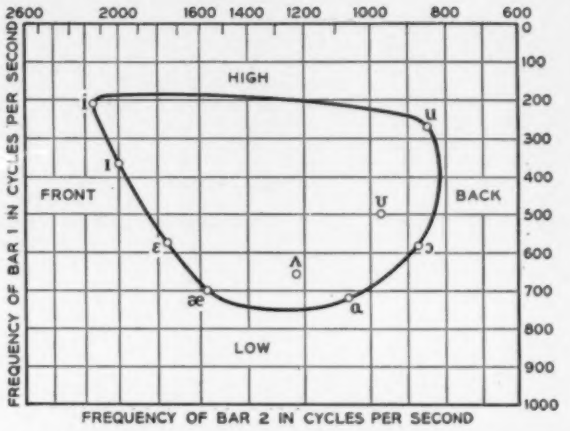


FIG. 17. Vowel loop obtained by plotting the second formant frequency against the first for various vowels. There is a close resemblance here to the vowel loop used by phoneticians to represent the vowels with respect to tongue hump position—high versus low, and front versus back.

"AUDREY"

The seventh type of device to be reviewed here in the series started at the Bell Telephone Laboratories is "Audrey," the automatic digit recognizer.[17] Fig. 23 shows, in schematic form, an early phonetic recognition circuit for 10 sounds. This device goes beyond those described above in that an attempt was made, not only to produce the underlying telegraph patterns of speech, but also to recognize automatically the particular sound or phoneme at each instant and then proceed—more particularly—to *word* recognition for a limited vocabulary, as in the digit recognition required in voice dialing.

The first step of automatic phoneme recognition is intensely important, for there is involved the goal of the free conversion of the spoken word to the written word, with entire new vistas opening up in the interchange of communication symbols.

RCA[18] and others are designing apparatus for the reverse process of translating from the written, or printed, or tape-perforated word to the *spoken* word.

There is thus possible a large area of two-way interchange between the spoken and written word and, accordingly, between the telegraph—for the written visible word—and the telephone—for the spoken audible word. These developments justify hope that in the distant future instrumentation will be developed for wide use of the written audible word and the spoken visible word.

Audrey reveals the phoneme recognized as well as the digit or word. Fig. 24 is an enlarged frame from a motion picture showing how, with a modest 10-sound repertory—sufficient for good digit recognition—the sound *a* as in *father* is indicated by the lighting of a lamp behind a representation of the recognized sound. There are also other lamps to indicate the digit recognized. As the film shows, when Audrey is adjusted for a particular voice, it gives almost perfect digit recognition. Scores of 98% and 100% have been obtained in two cases, but further improvement is needed for a wider variety of voices.

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[15] R. R. Riesz and L. Schott, "Visible Speech Cathode-Ray Translator"; H. Dudley and O. O. Gruenz, Jr., "Visible Speech Translators with External Phosphors," *J. Acoust. Soc. Amer.*, **17**, 50–73 (July 1946).

[16] L. O. Schott, "A Playback for Visible Speech," *Bell Laboratories Record*, **26**, 333–339 (August 1948).

‡ Mr. Borst's paper, "The Use of Spectrograms for Speech Analysis and Synthesis," will be published in a forthcoming issue of the JOURNAL.

[17] K. H. Davis, R. Biddulph, and S. Balashek, "Automatic Recognition of Spoken Digits," *J. Acoust. Soc. Amer.*, **24**, 637–642 (November 1952).

[18] V. K. Zworykin, L. E. Flory, and W. S. Pike, "Research on Reading Aids for the Blind," *J. Franklin Inst.*, **247**, 483–496 (May 1949).

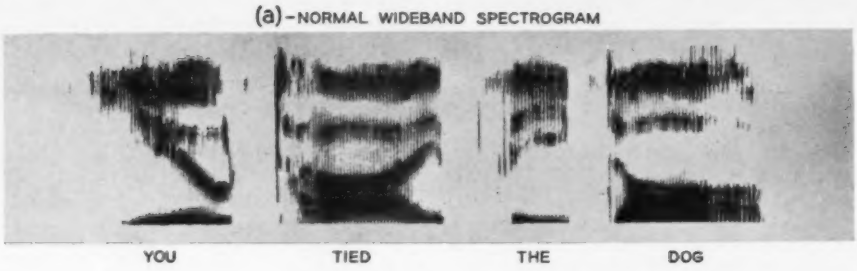

FIG. 18. Dynamic spectrograms of speech. The sentence spoken was, *You tied the dog.*

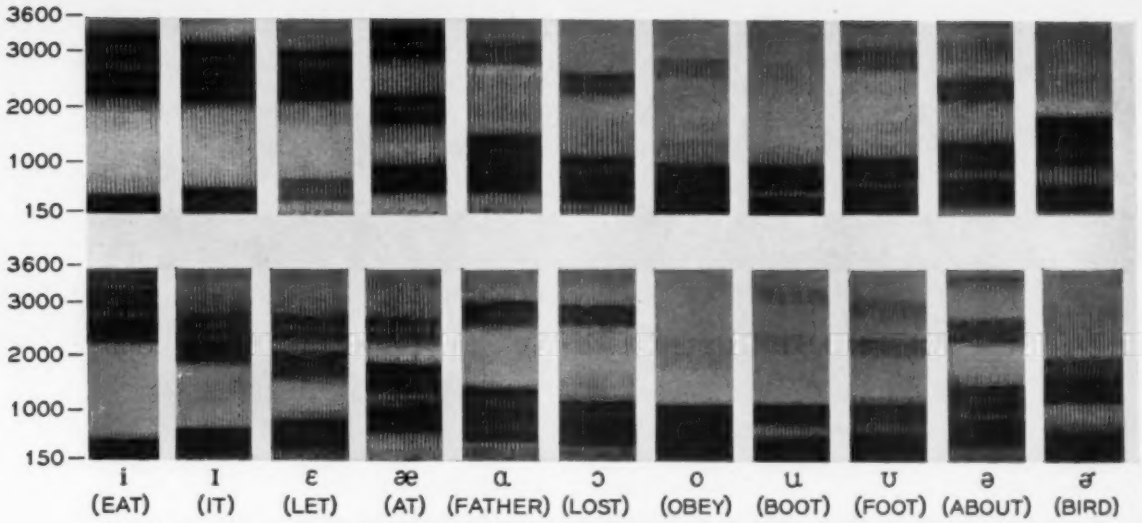

FIG. 19. Spectrograms comparing spoken vowels, below, with those made by Dunn's electrical vocal tract, above.

Of the seven devices reviewed, Audrey probably best brings out the telegraph nature of speech. Once a sound is recognized, the essential telegraph information is on hand, so that, from that point forward, the message can be handled as telegraph material on teletype tape or otherwise. The telegraph material can be stored, transmitted, received, stored again, and—when desired—it can ultimately be used for synthesis of audible speech messages for the ear; or the device can print tape with a visual message for the eye to read, presumably at higher speed.

Synthesis of speech is possible from the telegraph-like characters of the phoneme recognizer of Fig. 23. The Vocoder synthesizer produces such speech with a single switch energizing several spectrum channels of the Vocoder, each to the desired degree for that particular sound. A demonstration of speech synthesized by this method was given at the Sound Creation session of the AES convention. While, in the present state of the art, the quality of such speech is inferior, the production of any recognizable speech at all by this method portends the possibilities that this type of circuit offers, not only in speech synthesis but in selective control circuits operated by the voice. There are also possibilities

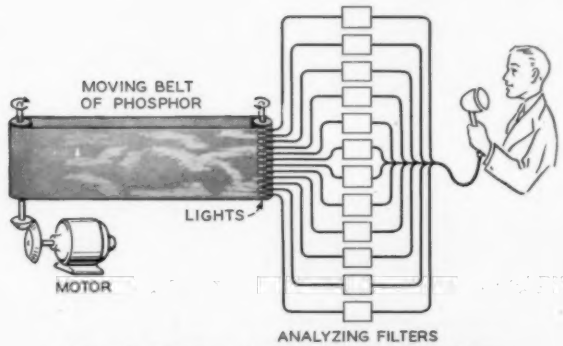

FIG. 20. Principle of the visible-speech translator.

FIG. 21. Training class before a large size visible-speech translator.

of application in automation and other apparatus under control of the spoken word.

IMPROVED VOCODER

Development of new devices for speech analysis-synthesis does not tell the whole story. Very important is the improvement of the earlier models. Nowhere has this been so marked as in the Vocoder; R. L. Miller has demonstrated an improved model so good that, when it has been publicly demonstrated,[19] listeners have had considerable difficulty in telling whether a selected talker was speaking directly or through the Vocoder. For comparison, spectrograms of the words *she sat up with you* are shown in Fig. 25 for the three conditions:

1. For original direct speech.
2. For the improved 16-channel Vocoder, using frequency bands as determined by the Koenig scale for equal contributions to intelligibility.
3. For the early 10-channel uniform-band Vocoder.

There are still outstanding some problems in application to a commercial telephone circuit with its nonlinearity, noise, limited speech band, and wide variety both of talkers and of circuit conditions to be handled.

[19] R. L. Miller, "Improvements in the Vocoder" (abstract), *J. Acoust. Soc. Amer.*, **25**, 832 (July 1953).

FIG. 22. Speech synthesis from shadow patterns.

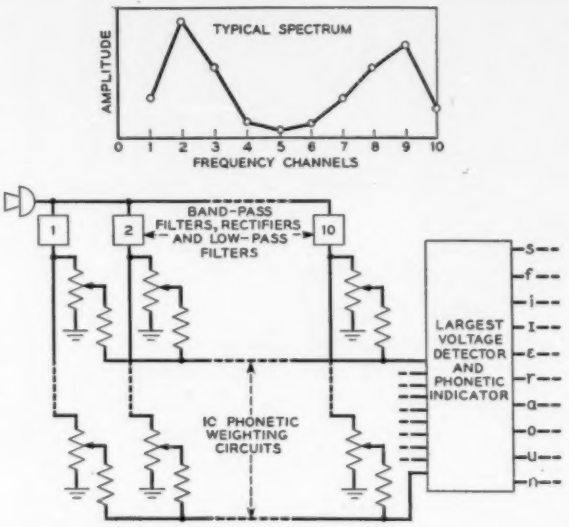

FIG. 23. Block schematic of the phoneme recognizer of "Audrey."

CONCLUSION

The devices described have made use of two basic principles:

1. That speech—in its first vibratory expression as muscular wave motion—is a set of telegraph signals.

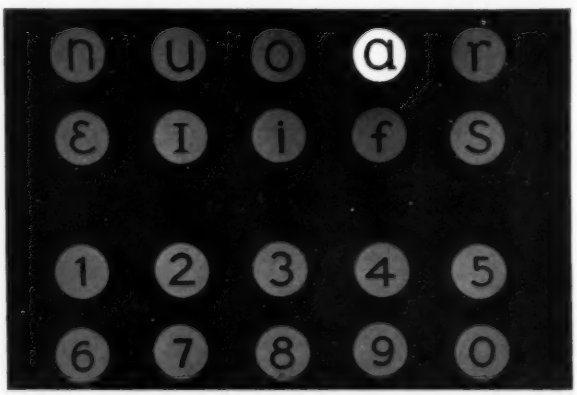

FIG. 24. Phonemic recognition of sound *a*, as in *father*, by "Audrey." A sustained sound was spoken. Signs for indicating the recognition of other sounds, and the digits, are also shown but not illuminated at the moment.

2. That advantage can be taken of this fact in speech transmission to conserve frequency space.

As successful work along these lines could lead to great savings to the telephone user of long lines circuits, the search for a wide variety of such devices goes on steadily. Under W. E. Kock's leadership, a number of brilliant young scientists have been enrolled in this pursuit of analysis-synthesis in its various aspects, so that the activity is undoubtedly at a higher level now than at any earlier time in the past twenty years.

This augurs well for the future of speech synthesis applied to telephone transmission and to other fields, as well.

Much of the work described has been that of many of my co-workers at the Bell Telephone Laboratories, who, with a few exceptions, have not been named but who, nevertheless, have been responsible for the progress made by the Laboratories in this quest.

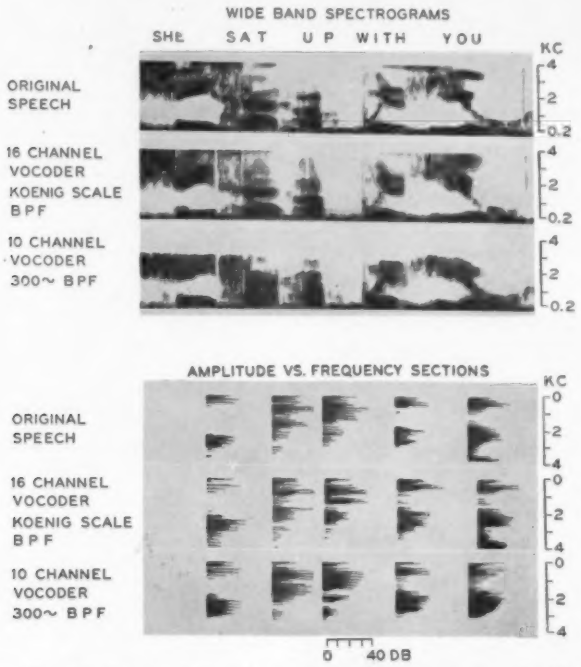

FIG. 25. Improved Vocoder speech spectrogram compared with that for direct speech and for the early Vocoder.

Magnetic Properties of Recording-Tape Pigments*

J. GITTLEMAN
The Franklin Institute Laboratories for Research and Development, Philadelphia, Pennsylvania

The magnetic properties required by a potential pigment for magnetic recording tapes are discussed from the point of view of high intrinsic sensitivity. It is pointed out that a high maximum slope of the remanence curve of the pigment is synonymous with high sensitivity, and the respective roles of the coercive force and the saturation remanence in determining this slope are discussed. The geometric characteristics of commercial pigments of γ–Fe_2O_3, which govern these properties, are demonstrated. These characteristics are summed up by the statement that the individual particles of the pigment must behave like single-domain particles. This is achieved in most American pigments with particles which approximate prolate ellipsoids of revolution measuring about 0.5 × 0.1 micron. Discussed, too, is a German pigment which possesses particles that are roughly spherical and measure about 0.06 micron in diameter.

The influence of the manufacturing processes on the sensitivity of the final product is examined, and data correlating tape sensitivity with all of these factors are given. The factors included in this correlation are the maximum slope of the remanence curve of the pigment, the density of the particles in the tape coating, the coating thickness, and the degree of pigment orientation.

INTRODUCTION

IN THE recording-tape manufacturing industry, the terms "acicular" and "single-domain" have become household adjectives in describing the ferromagnetic powders with which the recording tapes are produced. Actually, these adjectives pertain to the geometric properties of the particles that make up the pigment, roughly describing the size and shape of the particles. Figure 1 is an electron micrograph of a magnetic pigment stripped from a commercial tape. It can be seen that the particles are elongated, having average dimensions of about 0.5 × 0.1 micron. Particle shape and size are important only insofar as they are responsible for those magnetic properties which are desirable in magnetic-tape pigments. It is our purpose to discuss these properties and the ways in which they can be realized.

NOMENCLATURE AND DEFINITIONS

Before entering into a discussion of the magnetic properties of tape, it may be well to define some of the terms that are used.

1. *Magnetic moment.* The magnetic moment is a measure of the strength of a magnetic dipole and is defined by the maximum torque it experiences when placed in a unit magnetic field. In the laboratory, the magnetic moment of a specimen is usually measured by the electromotive force it induces in a coil. Most texts refer to *magnetization,* or *magnetic moment per unit volume,* when discussing the magnetic properties of a substance. However, when dealing with powders, where a precise determination of the volume is difficult, it is usually more convenient to speak of the *magnetic moment per gram,* or *specific moment.*

2. *The normal induction curve.* If an initially unmagnetized ferromagnetic specimen is exposed to successively

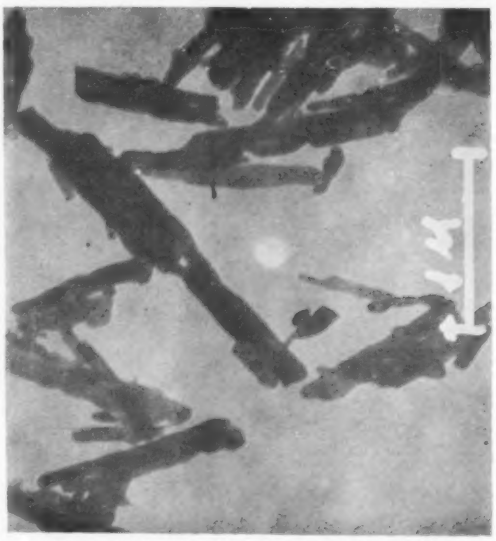

FIG. 1. Electron micrograph of a commercial recording-tape pigment.

* Presented at the Seventh Annual Convention of the Audio Engineering Society, New York, October 12-15, 1955.

larger and larger magnetic fields, the magnetic moments thus obtained, when plotted against the magnetic field, give a curve that is called the normal induction curve. A typical curve for magnetic recording pigments is shown in Fig. 2.

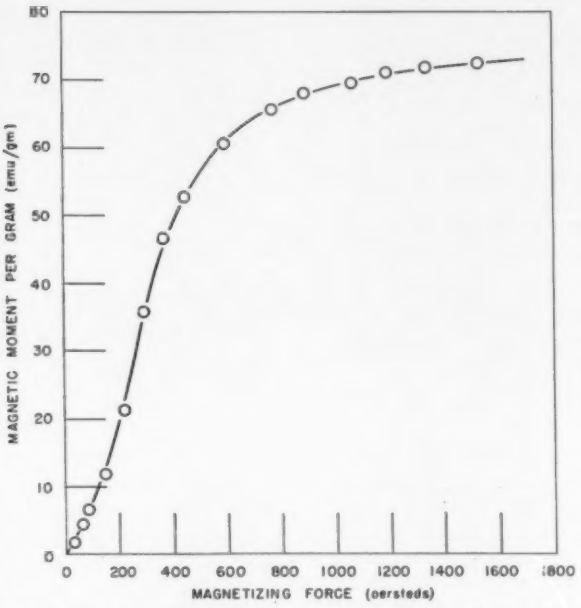

FIG. 2. A typical normal induction curve for magnetic-recording pigments.

The value of the moment in the limit of very high magnetic fields is called the *saturation moment* and is a fundamental property of the material.

3. *The remanence curve.* If an initially unmagnetized ferromagnetic specimen is exposed to a magnetic field which is then removed, the specimen exhibits a magnetic moment called its remanence. A plot of the remanence as a function of the magnetizing field is called a remanence curve. A typical curve for magnetic recording pigments is shown in Fig. 3.

4. *Coercive force.* If a ferromagnetic specimen, which has been magnetized to saturation, is exposed to a magnetic field which opposes the magnetic moment of the specimen, the value of the field for which the magnetic moment vanishes is called the coercive force.

5. *Single-domain particle.* According to modern theory, a ferromagnetic specimen is, at all times, spontaneously magnetized to its saturation value. The specimen is observed to have an unmagnetized state because, in general, it is composed of many domains which are themselves magnetized to saturation but whose moments are so directed that the overall magnetic moment of the specimen is zero. When a ferromagnet is smaller than a certain critical size, it is composed of only one domain and hence is incapable of being demagnetized. In the absence of an applied magnetic field, the ferromagnet is magnetized to its saturation value in one of several possible directions called the "*easy directions of magnetization.*"

THE IMPORTANT PARAMETERS

According to Camras,[1] the maximum sensitivity of a magnetic tape is proportional to the maximum slope of its remanence curve. Tests made at this laboratory indicate that there is a correlation between the maximum sensitivity of magnetic tape and the maximum slope of the remanence curves of the pigments from which the tape is made. For purposes of measurement, the pigment was packed in a glass tube so that the "easy directions" of the particles were randomly oriented. The magnetic moment was measured by withdrawing the specimen from a pickup coil and observing the deflection of a ballistic galvanometer to which the coil was connected.

Referring again to Fig. 3, it can be seen that the para-

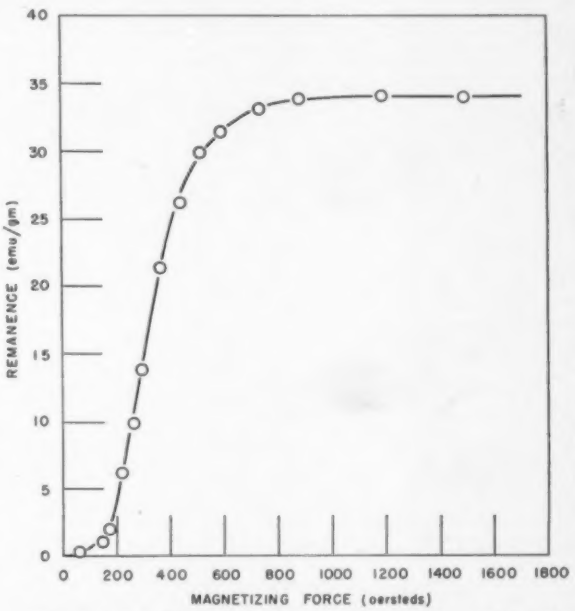

FIG. 3. A typical remanence curve for magnetic-recording pigments.

[1] Marvin Camras, "Graphical Analysis of Linear Magnetic Recording Using High-Frequency Excitation," *Proc. I.R.E.*, 37, 569 (May 1949).

meters affecting the steep portion of the curve are the saturation remanence and the fields at which the knees of the curve occur. To insure a maximum saturation remanence for a given material, it is necessary for this material to be in the form of a collection of single-domain particles.

Repeated observations of remanence curves of many different materials reveal that a relationship exists between the positions of the knees and the coercive force. A high coercive force tends to spread the steep portion of the remanence curve over a large range of field values and hence cause a low value for the maximum slope. Conversely, for a low coercive force, the steep portion of the curve is confined to a small range of field values and hence has a high maximum slope.

The saturation remanence and the coercive force, however, are not entirely independent of one another. Consider, for example, γ-Fe_2O_3 powders, the commonly accepted standard material for use on tapes. In order to insure that the powder exhibits the highest possible remanence, the particle size is chosen so that the powder behaves as a collection of single-domain particles. The minimum coercive force obtainable for such a pigment seems to be about 200 oersteds. In order to decrease the coercive force below this value, it is necessary to increase the particle size to such values that the particles are no longer single-domain. If this is done, the advantage expected as a result of the lowering of the coercive force is more than offset by the lowering of the saturation remanence.

Fig. 4 is an electron micrograph of a γ-Fe_2O_3 pigment similar in its properties to the pigment used on the original German recording tapes. It can be seen that this pigment possesses particles which do not have the shape factor common to the typical pigments used today, although the particle size is in the same range. Although the saturation moment of this pigment is the same as that of modern pigments (about 75 emu/gm) and it exhibits a low coercive force (about 90 oersteds), its saturation remanence is exceedingly low, being around 45% less than that observed for the modern pigments. On tape, the low-frequency sensitivity of this pigment is from 6 to 10 db less than that of modern tapes.

THE GEOMETRY OF MAGNETIC PIGMENTS

It should not, however, be concluded that a good γ-Fe_2O_3 pigment must be composed of particles which are approximately prolate ellipsoids of revolution having dimensions of the order of tenths of microns. In the case of the standard pigment, each particle has two easy directions because of its shape. These directions are the two antiparallel directions defined by the long axis of the particle. In this case, the expected value of the saturation remanence, when measured on specimens containing randomly oriented particles, is one-half of the saturation moment, or about 37 emu/gm for γ-Fe_2O_3. Actual measurements indicate a saturation remanence value between 34 and 37 emu/gm for these pigments.

Single-domain particles need not have the prolate ellipsoidal shape. A spherical particle, if made small enough, can contain a single ferromagnetic domain. In this case, the easy directions are determined by the crystalline structure of the materials. In γ-Fe_2O_3, the structure is cubic and the easy directions coincide with the cube axes. Because of this multiplicity of easy directions, the saturation remanence (measured on specimens having randomly oriented easy directions) should be about 0.8 of the saturation magnetization, a much higher value than for the prolate ellipsoids. Thus a γ-Fe_2O_3 pigment composed of spherical single-domain particles is potentially more sensitive than pigments made up of prolate ellipsoids.

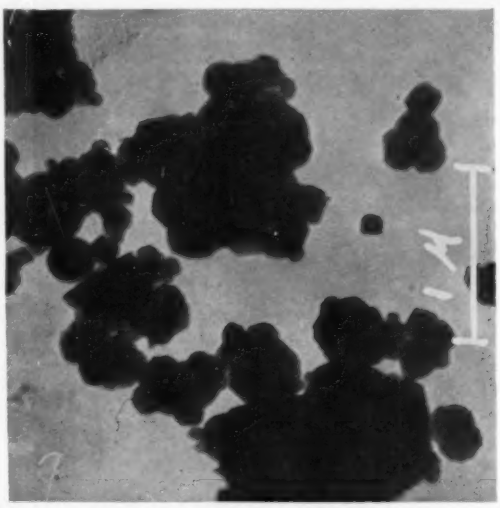

FIG. 4. An electron micrograph of a pigment having properties similar to the old German pigments.

Fig. 5 is an electron micrograph of a pigment obtained from a modern German tape (Agfa SST). It is composed of tiny spheres having an average diameter of about 0.06 micron, considerably smaller than the standard American pigments. Although the German pigment has a saturation moment which is somewhat lower than that of the American pigments and a rather high coercive force (365 oersteds), the German specimen has a remanence curve slope comparable to those of the American pigments. This high slope is attributable to a very high saturation remanence. The low-frequency sensitivity of the German tape however is about 3 db less than that of most American tapes.

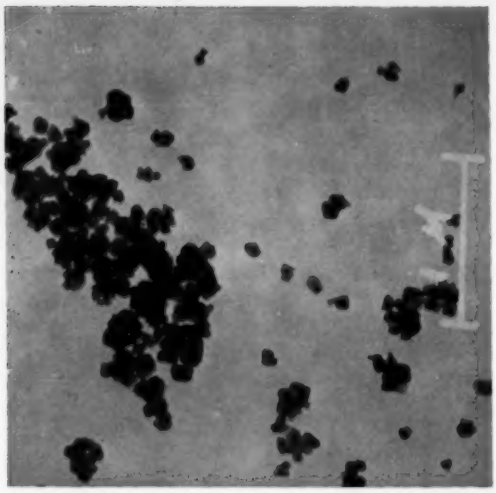

FIG. 5. An electron micrograph of a modern German pigment (Agfa SST).

In the final analysis, it is the shape of the remanence curve on the tape that determines the sensitivity of the tape. Here, other factors, which are as important as the pigment itself in determining the tape sensitivity, come into play. The maximum slope of the remanence curve can be increased over that which we measure for the pigment by coating the tape in such a way as to make the tape axis a preferred direction for the easy directions of the particles. All of the leading manufacturers of magnetic tape attempt to orient the pigment on the tape. Thus, the ratio of saturation remanence to saturation magnetization measured along the tape falls between 0.6 and 0.7 instead of the 0.5 ratio secured for our randomly oriented specimens.

Also, the sensitivity will depend on the density of the particles. The larger the number of particles per unit length of tape, of course, the greater will be the recorded flux and the higher will be the sensitivity.

Finally, at long wavelengths, at least, the thickness of the magnetic coating will affect the sensitivity. Thus, the thicker the coating, the greater will be the recorded flux and the higher will be the tape sensitivity.

COMPARISON OF NINE DIFFERENT SPECIMENS

Table I gives all of the measured properties which were deemed important, from nine different specimens. There are several interesting features to be noted. Sample A has a maximum remanence curve slope considerably less than most of the other samples, and yet its low frequency sensitivity is very high. This can be accounted for almost entirely by its high coating density.

Sample B exhibits very high sensitivity, although the slope of its remanence curve is about the same as that of other standard pigments. This seems well accounted for by its high degree of pigment orientation, as can be seen by the ratio of remanence to saturation value obtained from the tape, by its unusually high coating density, and its greater coating thickness.

Sample F is a specimen obtained from a Mylar-based tape. Its low remanence-curve slope and small coating thickness are partially offset by a high coating density.

Sample H is a pigment composed of very small ($\sim .06\ \mu$), roughly spherical particles. This pigment is distinguished by low saturation moment, very high saturation remanence, and by a low sensitivity which cannot be accounted for by the parameters thus far discussed. It should be noted that the coercive force of this pigment is rather high, giving rise to a high optimum bias current.

Sample I is the large, irregularly shaped pigment which was discussed previously. It is distinguished by very low sensitivity, which is completely due to very poor remanence

TABLE I. Measured Properties of Several Tape Pigments.

Sample	Maximum Slope of Remanence Curve (egs)	Maximum Slope of Normal Ind. Curve (egs)	σ_s† (emu/g)	σ_r‡ (emu/g)	H_c§ (oersteds)	Optimum Bias (ma)	σ_r/σ_s on Tape	Sensitivity in db at 300 cps and 15 ips	Thickness of Tape Coating (mils)	Coating Density (g/cc)
A	0.0995	0.163	72.2	34	230	80	0.642	11.8	0.67	2.13
B	0.132	0.176	73.1	36	248	90	0.723	14.4	0.75	2.47
C	0.137	0.153	73.9	36	260	90	0.632	10.0	0.60	1.87
D	0.133	0.171	72.1	35	255	100	0.644	9.0	0.65	1.87
E	0.137	0.147	73.7	35	253	90	0.679	9.6	0.65	1.54
F	0.093	0.124	69.9	32	258	75	0.631	8.0	0.40	1.94
G	0.114	0.147	70.9	32	224	80	0.651	10.0	0.65	1.96
H (Agfa SST)	0.134	0.138	65.5	48	365	105	0.71	6.2	0.50	1.89
I (Old German)	0.076	0.160	72.4	20	95	60	0.27	4.3	0.65	2.41

† σ_s = Saturation Moment ‡ σ_r = Saturation Remanence § H_c = Coercive Force

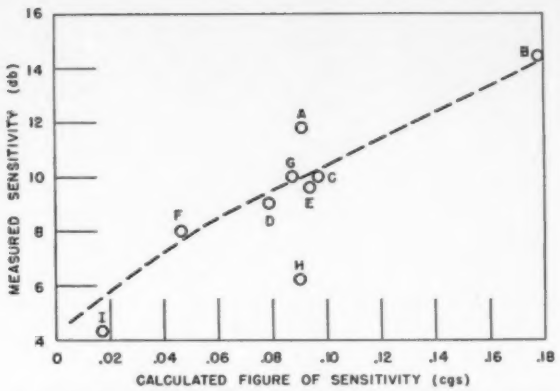

FIG. 6. Correlation between low-frequency sensitivity and parameters affecting the recorded flux.

properties. The particles are too large (for their shape) to behave as single-domain particles, and this, no doubt, accounts for these poor properties.

An attempt was made to show the correlation between the tape sensitivity and the parameters which affect the recorded flux, i.e., the maximum slope of the remanence curve, the ratio of remanence to saturation on the tape (a measure of the degree of orientation), the thickness of the tape, and the coating density (a measure of the amount of magnetic material per unit volume). Fig. 6 is a plot of sensitivity against a product of all the above-mentioned parameters. The trend in the points is shown by the dashed curve. Although the scatter is large, only Sample H fares badly. Since all of the manufacturing variables which can affect the tape sensitivity probably have not been included, and since a direct product of all the factors that have been included may tend to overemphasize the effect of one or more of the factors, we believe that the correlation is a fairly good one.

SUMMARY

In summary, when seeking a potential pigment for use on recording tape, certain properties must be sought to insure maximum steepness of the remanence curve and hence maximum inherent sensitivity in the pigment.

First, the pigment must be composed of particles which behave like single-domain particles. This insures a maximum value of saturation remanence for a given material. The size and shape of each particle are important only insofar as size and shape determine saturation remanence.

Finally, the pigment must be of a material which exhibits a coercive force that is as low as possible. It is fortunate that a pigment as economical to produce as γ-Fe_2O_3 has a coercive force that is as low as it is (~250 oersteds). Single-domain iron, for example, shows a coercive force which is from three to five times that of γ-Fe_2O_3. Thus, in spite of its exceptionally high saturation remanence, single-domain iron exhibits a low maximum remanence curve slope.

In conclusion, it must be added that, for reasons other than those of sensitivity considerations, a coercive force cannot be chosen which is either too large or too small. A tape made from a pigment having a very *high* coercive force—say, in excess of 400 oersteds—would require unusually large ac bias values and would be especially difficult to erase. A tape made from a pigment with an unusually *low* coercive force—less than about 50 oersteds, for example—although quite sensitive, would be greatly affected by stray fields and would probably exhibit high print-through characteristics.

Standards of Acceptability For High-Fidelity Loudspeakers*

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INTRODUCTION

THE AMERICAN Standards Association and the British Standards Institution have both laid down recommendations for ascertaining and expressing the performance of loudspeakers. In the main, both the standards concerned (ASA C16.4-1942 and BSI 2498-1954) agree on the nature of the tests required, although the British standard goes into rather more detail.

The following quantities are listed for determination:

1. Frequency response and directional characteristics.
2. Electrical impedance characteristics.
3. Non-linear distortion characteristics.
4. Efficiency.
5. Power-handling capacity.
6. Transient performance.

Clearly, a loudspeaker specification carrying information on all these quantities would be of great value and interest to the potential user. This would still be true in spite of the fact that all measurements had been taken under "idealized" conditions and could not always be directly related to local conditions of use.

However, one never finds a published loudspeaker specification nearly as comprehensive as that proposed, and the reason for this is not hard to find, namely, there is a disinclination on the part of manufacturers to publish information other than that which they know to be acceptable. It would appear that this state of affairs will continue to exist until sets of "minimum" performance figures are laid down by an appropriate authority.

It is proposed to discuss such performance figures, and to make suggestions for suitable lower limits. The discussion will be limited to high-fidelity loudspeakers.

Quite obviously, there are ideal performance figures which may be aimed at, and these are known quantities; but, in the present state of the art they are not achieved. It could be fairly argued that minimum performance figures would be those which the ear is incapable of discriminating from the ideal figures, in the case of a loudspeaker operating under fixed, specified, conditions. Even this cannot be achieved in all the respects listed; so, the practical limits must be reduced somewhat. The essential objective is to provide a specification which will ensure that the high-fidelity label really means something and is not used indiscriminately.

We will deal with the various performance features in the order in which they are listed above.

1. FREQUENCY RESPONSE AND DIRECTIONAL CHARACTERISTICS

Both these characteristics should be measured under free-field conditions and the mounting conditions specified. The microphone should be placed at a distance of not less than 3 ft from the loudspeaker.

The frequency-response characteristic is taken as meaning the "on-axis" pressure response for a constant-voltage electrical input. A response of 20 cps to 20,000 cps, within small limits of variation, can be (and has been) obtained for the axial response. From the point of view of minimum acceptable requirements, a minimum range of 40 cps to 12,000 cps is suggested, with variations of less than ± 5 db. Wider variations than this, particularly in the form of a gradual rise in the treble register, should be acceptable in those units intended for diffused operation, or where there is a special irregularity in the polar characteristic. In these cases, the inference is that the mean spherical response or the mean hemispherical response is essentially uniform.

Polar Characteristics

The polar characteristics are best presented by polar diagrams at appropriate frequencies, but, it is thought that a more convenient presentation—from the point of view of publication of the information—would be in the form which

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† Chief of Research.

gave the total angle within which the response does not vary by more than ±5 db (for example) at the stated frequency. It is suggested that these frequencies be 1000 cps, 5000 cps, and also the frequency quoted as being the upper response limit of the loudspeaker in question.

At 1000 cps this angle should be greater than 160°. At 5000 cps the minimum total angle proposed is 100°. For the upper response limit (which may, for example, be 12,000 cps, 15,000 cps, or 20,000 cps) it is difficult to lay down a minimum angle, as this will depend on frequency. In any case, values should not fall below about 50°, for single units. In the case of a multiple-speaker system, or one employing treble-diffusion arrangements, this figure will be much improved.

2. ELECTRICAL IMPEDANCE CHARACTERISTICS

Present amplifier technique makes it unnecessary to provide an absolutely flat impedance characteristic. However, it is generally agreed that impedance variation of the complete loudspeaker system (that is, including cabinet or other loading arrangements) should be as small as possible. It is usual for high-fidelity loudspeakers to be designed to provide their required response with a constant-voltage input, since this is the condition which obtains with most high fidelity amplifiers. Impedance variation, therefore, is already taken into account from the standpoint of its effect on response, but not from the point of view of its influence on the optimum working conditions of the amplifier. Thus, the expression of curves of both modulus and phase angle would be the most useful form of presentation.

3. NONLINEAR DISTORTION CHARACTERISTICS

Non-linear distortion is the description applied to any departure from proportionality between the acoustic output and the electrical input of the loudspeaker. In the case of a single frequency input, it may be exhibited by the production of harmonics and subharmonics, the latter being the name given to integral submultiples of the fundamental frequency.

The measurement of these forms of distortion is comparatively simple. In the case of a multiple-frequency or complex-wave input, intermodulation products will also be obtained in the output. The accurate measurement of intermodulation distortion is not a task which can be satisfactorily carried out by all laboratories.

Consequently, it is proposed that harmonic distortion should be measured and quoted in all cases, and intermodulation distortion when possible.

Harmonic distortion tests should be taken at a stated level of input power. The fundamental frequencies for which distortion measurements should be made will differ in individual cases. It is recommended that measurements be made at the frequency of maximum excursion of the diaphragm, and at other frequencies up to, say, 10,000 cps.

Investigations show that it should be possible to specify an upper limit of the order of 3% for total harmonic distortion, at half the maximum rated power-handling capacity. It will be understood that most high-fidelity loudspeakers will actually show better performance than this at most frequencies and may very well be worse at one or two spot frequencies. It is because of this that it is not possible to specify all the frequencies at which distortion measurements should be taken; it is therefore a matter of the integrity of the individual manufacturer to quote what he regards as a truly representative distortion figure. In this respect it should be remembered that 3% harmonic distortion is normally easily audible at most frequencies!

Intermodulation Measurements

Intermodulation measurements are performed by the simultaneous application of two frequencies to the loudspeaker and by analysis of the resulting acoustic output. Without special apparatus, the procedure becomes long and tedious if tests are carried out with more than one pair of frequencies. It is felt that a useful guide to distortion characteristics may be had by the choice of one pair of suitably chosen frequencies. The lower of the two frequencies may be the bass resonant frequency. The upper frequency should be high enough to fall within the range of the treble unit for two-unit systems. The upper frequency should be placed about an octave above the crossover point. If more than two speakers are involved, then the test will have to be repeated with different upper frequencies, on the same basis. The amplitude of the lower frequency may be four times that of the higher frequency.

Although a maximum figure has been proposed for harmonic distortion, it is not intended to quote permissible intermodulation distortion at this point, not only because it is felt that few manufacturers are able to measure this quantity satisfactorily, but also because there is, as yet, no agreement regarding the method by which results should be weighted to give a nearer approach to the aural impression of the distortion.

4. EFFICIENCY

There are two possible definitions of the efficiency of a loudspeaker: One defines efficiency as the ratio of the total acoustic power radiated to the electrical power input at a stated frequency. The other defines efficiency as the ratio of the total acoustic power radiated to the electrical power which would be dissipated by a resistance, equal in magnitude to the modulus of the impedance of the loudspeaker at 400 cps, if this resistance were substituted for the loudspeaker without any other change in circuit conditions.

The first of these definitions is probably the more useful one for our purpose, since it does not require us to take into account differing amplifier characteristics. The first definition also ignores the effect of the impedance characteristics of the loudspeaker, but these will have been quoted in any case.

It is not necessary to quote the efficiency in every high-fidelity loudspeaker specification, but it should be stated in the case of special units, e.g. woofers and tweeters, which may well be used in conjunction with units of different manufacture. In this respect it is worth noting that it is not necessary to provide anything other than a *relative* efficiency figure. A knowledge of *absolute* efficiency does not appear to have any appreciable significance in most high-fidelity applications, where driving power is not normally at a premium.

5. POWER-HANDLING CAPACITY

The power-handling capacity of a loudspeaker may be limited by (a) damage or (b) excessive distortion. It is usual for the excessive-distortion point to be reached before damage occurs, but in any case, the effect which arises first will be the limiting factor.

Thus, it is suggested that the particulars of power-handling capacity should be quoted in one or both of the following ways:

(a) Frequencies and maximum amplitudes of voltage or current—of sinusoidal input waveform—which can be applied continuously (for example, for not less than 100 hours) without damaging the loudspeaker. Details of mounting should be stated.

(b) The input at which the total rms value of the distortion products does not exceed a stated percentage of the rms value of the fundamental (as measured by a single-frequency distortion measurement) at any frequency within the stated range. It is suggested that the allowable distortion determining the maximum power input should be of the order of 5%.

The disadvantages of both these methods of defining power handling capacity are 1. that they are based on single-frequency inputs; 2. that they take no account of the effects of shock excitation.

It is difficult to visualize a satisfactory and acceptable test that would cover these points.

6. TRANSIENT PERFORMANCE

Transient response may be defined as a description of the response as a function of time during the transition between two steady states, caused by a sudden change of stimulus.

If a series of interrupted wave trains is fed to the loudspeaker, and the acoustic output is measured at a time t seconds after the interruption, then the decay factor can be determined, assuming an exponential decay. This factor should be determined at as many frequencies as possible. Apparatus is available which automatically plots the decay curves at small intervals throughout the frequency range of the loudspeaker.

Alternatively, the transient performance may be expressed in the form of a "delayed" response curve, with the points plotted to form the curve representing output from the loudspeaker at a fixed, stated interval from the time of interruption of the electrical signal.

In cases where it is not possible to carry out either of the above procedures, a statement of the equivalent external resistance required to produce critical damping at bass resonance should be given. This may be determined from a knowledge of the mechanical reactances existing in the equivalent analogous circuit of the loudspeaker, referred to the voice-coil terminals.

CONCLUSION

It must be emphasized that the suggestions detailed above have been put forward with the hope that they may provide a basis from which discussions can go forward. If, as a result of such discussions, a reasonable measure of standardization of minimum performance requirements for high-fidelity apparatus can be brought into being, on an *international* basis, then the object of these proposals will have been achieved.

On Electrical Loading of Microphones*

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Electrical loading of microphones by preamplifier circuits has not been of great concern to the audio engineer, heretofore. In the past, the input impedance of preamplifiers has been so much higher than the output impedance of microphones that the effect upon the performance of microphones has been indeed negligible.

The recent appearance of transistorized preamplifiers whose input impedance is sometimes quite low, and the growing use of high-sensitivity ribbon microphones which have a highly frequency-variant output impedance has stimulated new interest in this loading problem. A study of the Thévenin equivalent circuit of certain common types of broadcast microphones discloses that the input impedance of a preamplifier must be maintained at a value at least five times the nominal impedance of the microphones with which the preamplifier may be used—in order to avoid undesirable alteration of the microphone's frequency-response characteristic. This applies unless the preamplifier has been designed for a particular microphone.

THE TECHNICAL DATA supplied to the consumer on microphone characteristics generally contain no discussion of the effects of the electrical load upon these characteristics. Seldom, if ever, is an "output impedance versus frequency" curve supplied, which would enable the user to calculate the effects of electrical loading. The manufacturer's assumption is that the studio equipment will present what is essentially an open circuit to the microphone. The "low-impedance" input terminals of a conventional vacuum-tube preamplifier do effectively offer a high impedance load to the microphone, because the primary inductance of the input transformer is normally very high, and the capacitive load on the primary and secondary of the transformer is generally slight.

LOAD IMPEDANCE

Figure 1 is a curve of input impedance versus frequency of a standard 250-ohm vacuum-tube studio preamplifier. It can be assumed that the load presented by this preamplifier to a 250-ohm microphone is negligible.

Transistorized preamplifiers, on the other hand, are generally characterized as having a resistive input impedance, an impedance essentially independent of frequency. In order to obtain the highest possible gain, it is desirable that the input impedance approximately equal the nominal impedances of the assortment of microphones with which the preamplifier may be used. Higher input impedances at the preamplifier normally result in reduced gain.

MICROPHONE IMPEDANCE

How is a microphone's frequency response affected by the electrical load of these two types of preamplifiers, i.e., vacuum-tube preamplifiers and transistorized preamplifiers? It is obvious that a microphone whose output impedance is essentially resistive and independent of frequency will be unaffected by a resistive load, or by the loading of the preamplifier of Fig. 1, whose impedance at frequencies of interest is very much higher than the microphone's impedance.

Moving-coil dynamic pressure microphones have essentially resistive output impedances and so do not concern us here. Condenser microphones require specially designed exciter-preamplifiers, which are beyond the scope of this paper. There remains but one type of broadcast microphone,

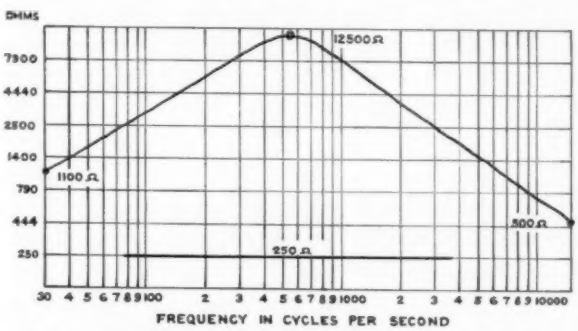

FIG. 1. Input impedance plotted versus frequency for the 250-ohm terminals of a standard vacuum-tube studio preamplifier.

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† Engineer, Transducer Design Group.

the ribbon microphone, which *does* have an output impedance which varies widely with frequency. This variation in output impedance is inherent in all bidirectional and unidirectional ribbon microphones and is normally encountered in nondirectional, pressure-actuated, ribbon microphones.

THE RIBBON MICROPHONE

Let us study the bidirectional ribbon microphone for a moment to see why this is so. The ribbon in a bidirectional microphone is a conductor in a magnetic field whose generated voltage is proportional to its velocity. For an output which is independent of frequency, the velocity of the ribbon must be independent of frequency. The ribbon is exposed on both sides (front and back) to the sound field. Therefore, the net force on the ribbon is proportional to the instantaneous sound-pressure difference between the front and back of the ribbon. At a distance from the sound source, the absolute rms pressure is the same on both sides of the ribbon, since the dimensions across the front of the microphone are generally small compared to a wavelength of the frequencies of interest. The driving force must come, then, from the phase difference between the pressures at the front and back of the ribbon; this phase difference is proportional to frequency. If the distance from the front to the back of the ribbon is small compared with the wavelengths of the sound frequencies of interest, the driving force will also be proportional to frequency. Since the driving force is proportional to frequency and the velocity is to be independent of frequency, the mechanical impedance of the ribbon must be proportional to frequency, i.e., a mechanical inductance.

Figure 2 shows the mechanical circuit of a bidirectional ribbon microphone. B and l are the magnetic flux density and the length of the ribbon, respectively. The mass of the moving system (the mechanical inductance) is the controlling impedance; therefore the point at which it resonates with the compliance of the moving system must occur at a very low frequency. The electrical circuit of the microphone is also shown, and it can be seen that the magnitudes of B and l, respectively, determine the extent to which the mechanical impedance influences the electrical impedance. The higher the Bl product, the higher the output voltage, E. Unfortunately, with the ribbon resistance unchanged, the output impedance then becomes controlled to a greater extent by the mechanical impedance which—above the resonant frequency—is proportional to frequency. The impedance inversion resulting from the manner of transduction (electrical impedance equals B^2l^2 *divided* by the mechanical impedance) makes the electrical impedance increase with *decreasing* frequency. The electrical impedance is constant at higher frequencies, where ribbon resistance dominates, and increases at lower frequencies where Ce dominates. The higher the value of B^2l^2, the higher the efficiency and the higher the output impedance of the microphone at low frequencies.

We are, at this point, able to make some approximate predictions concerning load impedance. For example, if the load resistance should be equal to the microphone's impedance at resonance, there will be a 6 db attenuation at that frequency. And, if the ribbon resistance is small compared to this impedance (which would yield a very efficient microphone), the attenuation at higher frequencies will be negligible. The net result, therefore, is a loss approaching 6 db at low frequencies.

A TYPICAL RIBBON MICROPHONE

Let us look at the output impedance of one highly efficient

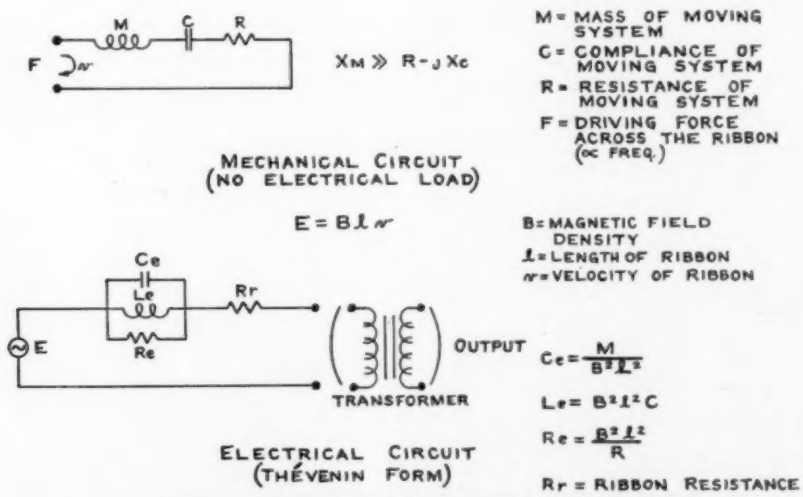

FIG. 2. Simplified equivalent circuit of a bidirectional ribbon microphone.

ribbon microphone (Fig. 3). This microphone has a directional characteristic which is adjustable by mechanical means. The nondirectional adjustment exhibits the least variation of impedance with frequency, since the microphone is then pressure-sensitive and the moving system is more nearly resistance controlled.

The series of lesser resonance at odd multiples of the fundamental are due to higher modes of vibration in the ribbon and are perfectly normal in a ribbon microphone. In high-quality ribbon microphones these higher-order modes are of a minor nature and do not detract from the excellent

MEASURING LOADING EFFECT

Since a mathematical determination of the effect of load impedance upon frequency response appears arduous, the alternative of direct measurement is chosen. The test circuit of Fig. 4 is a practical application of the Thévenin equivalent circuit of the microphone. The load impedance can be that of a particular preamplifier of interest or an adjustable impedance upon which a suitable design may be based. This circuit is useful, in practice, for determining the equalization necessary to compensate for the loading effect of a pre-

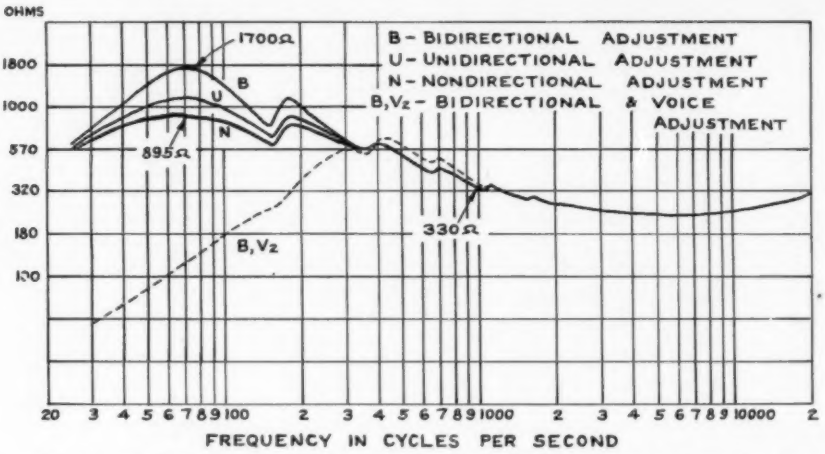

FIG. 3. Output impedance of a high-sensitivity ribbon microphone (nominal impedance, 250 ohms).

transient response and low distortion which are recognized as the outstanding attributes of the ribbon microphone. It is apparent, however, that these resonances complicate considerably the mathematical expression for the microphone's output impedance.

The particular microphone of Fig. 3 has a three-position switch allowing two degrees of low-frequency attenuation to compensate for the rise in low-frequency response which occurs when a bidirectional or unidirectional microphone is used in close proximity to the sound source. The lower curve in Fig. 3 illustrates the effect of this switch on the output impedance. This "voice" compensation is accomplished by placing an inductance across the microphone transformer.

It is apparent in these curves that loading the microphone with a resistive impedance will cause a reduction in low-frequency response of the *normal* microphone setting and an increase in low-frequency response of the microphone when adjusted for compensation of the proximity effect. The functioning of the VOICE-MUSIC switch is thus nullified.

amplifier designed for a particular microphone. The 5-ohm resistor is selected, normally, as being negligibly small compared with the microphone impedance.

Where accuracy of measurement requires it, a reference curve of the system's response may be taken by short-circuiting the microphone terminals.

It is important that the voltage appearing across the microphone terminals never exceed a few millivolts in order to prevent, not only nonlinear impedances resulting from high ribbon excursions, but also attendant damage to the microphone.

Data obtained in this fashion on this microphone are set forth in Figs. 5 and 6. Figure 5 gives the loading effect of the preamplifier of Fig. 1 which, as we had anticipated, is indeed negligible. Figure 6 shows the effect of various resistive loads upon our subject microphone for a few of its many available adjustments. The shapes of these curves are what we would have expected after our study of the output-impedance curves. Where the output impedance is highest,

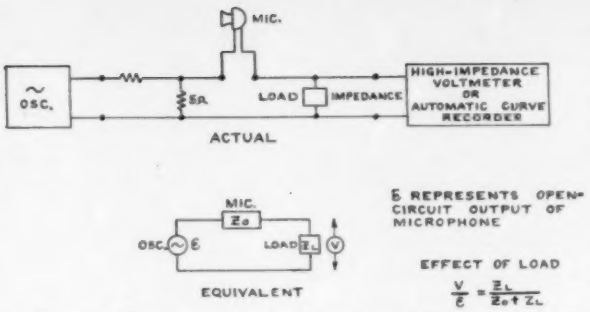

FIG. 4. Circuit to measure effect of load upon the frequency response of a microphone.

the output becomes lowest. For heavy loading, the VOICE adjustment becomes ineffective.

The load of 250 ohms—presumably a matching load—has a severe effect: a loss of almost 12 db at 70 cps in the bidirectional-music setting and a boost of about 4 db at this same frequency when the microphone is adjusted for close talking and bidirectional pickup.

With a load of 3000 ohms, the microphone is down only 3 db at 70 cps, which places the response within 1.5 db of the open-circuit response. Furthermore, the wiggles at the higher resonances have become insignificant.

Dropping the load impedance to 1500 ohms results in a loss of 5 db at 70 cps, which might be considered the absolute maximum allowable for broadcast purposes.

Notice that, as the load impedance is decreased below this value (which is approximately equal to the microphone's impedance at resonance) the frequency distortion increases rapidly. The marked differences among the 250-ohm curves preclude the use of equalization circuits to compensate for the loading effects of a low-input-impedance preamplifier. Individual equalization is required to compensate for each adjustment of the microphone, and further equalization is necessary to compensate for variations among similar types of microphones.

SUMMARY

The conclusions derived from these observations are:

1. A microphone preamplifier for general use must have an input impedance not less than the highest impedance appearing at the output terminals of any microphone with which it may be used, if a frequency-response deviation of less than 6 db is to be maintained. The maximum impedance of the microphone, in the present state of the art, can be as high as five times the nominal microphone impedance.

2. When a low-impedance preamplifier is being designed for use with a particular microphone having a frequency-sensitive output impedance characteristic, the effect of the load upon the frequency-response characteristic must be determined so that suitable equalization can be provided; this equalization will be suitable only for that particular microphone's output-impedance characteristic.

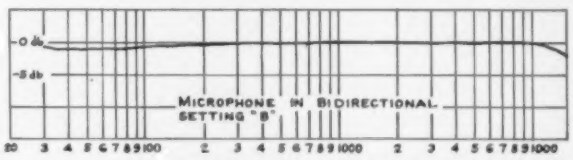
0 db
-5 db
MICROPHONE IN BIDIRECTIONAL SETTING "8"
20 3 4 5 6 7 8 9 100 2 3 4 5 6 7 8 9 1000 2 3 4 5 6 7 8 9 1000
FREQUENCY IN CYCLES PER SECOND

FIG. 5. Frequency response relative to no load. The microphone of Fig. 3 is loaded by the preamplifier of Fig. 1.

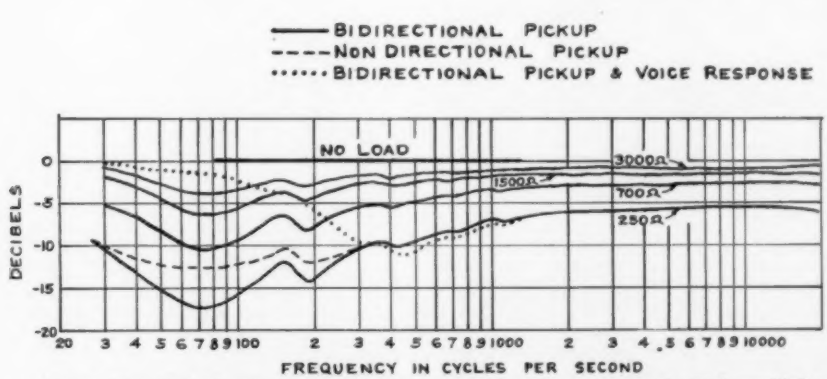

FIG. 6. The effect of various resistive loads upon the frequency response of a high-sensitivity ribbon microphone (nominal impedance, 250 ohms) adjusted in turn for bidirectional pickup, nondirectional pickup, and for a combination of bidirectional pickup and voice response.

A Transistorized Magnetic Tape Recorder*

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Radio Corporation of America, Camden, New Jersey

WITH THE advent of low-noise junction transistors, and the development of circuits which will compensate for variations due to temperature change, the transistor is replacing the electron tube in some areas of electronics. One such area is in audio applications. The transistorized tape recorder was developed to demonstrate some of the unique advantages of employing transistors in audio systems. The design problems encountered included those customarily associated with low-level inputs, high-gain amplifiers, and oscillators with output frequencies in the neighborhood of 50 kc.

In addition to good electrical performance, the transistor amplifier was extremely compact and lightweight. Low power requirements for transistors eliminated the need for a separate power transformer. A novel property of transistors called complementary symmetry allowed direct coupling of the output stage to the loudspeaker without the use of an output transformer.

A physical comparison of the tube model with the transistor version is shown in Fig. 1. Printed wiring and auto-assembly techniques were used to physically embody the transistor amplifier. Although the tape-drive mechanism is common to both models and dictated the final size of each, the transistor amplifier is small as compared with the conventional tube amplifier. The 6-lb reduction in weight resulting from transistorization effected a 25% decrease in the overall weight of the tape recorder, virtually eliminating the electronic portion of the recorder as a weight-contributing factor.

The complete circuit for the *record-playback* amplifier is shown in Fig. 2. Of the eight transistors used in the circuit only two, the PNP and NPN power transistors used in the output stage, are experimental.

The tape recorder described here is an experimental model. Using eight junction transistors, it equals or surpasses a conventional tube-type tape recorder in the performance criteria as shown by the following data:

TABLE I.

	Tube model	Transistor model
Signal-to-noise ratio	40 db	60 db
Power output 1000 cps	1 watt	1 watt
Distortion at 1 watt		
1000 cps	2.5%	2 %
100 cps	8 %	2.5%
Frequency response	100-8000 cps	50-8000 cps
Power consumption, idling	28 watts	.25 watt
Weight (of amplifier)	6.5 lb	0.5 lb
Weight of recorder	26 lb	20 lb
Tape speed	7½ ips	7½ ips

INPUT CIRCUIT AND CURRENT AMPLIFIERS

With the tape head driving a low-impedance transistor input, considerations for equalization are different here than in high-impedance tube practice. When connected to an essentially open circuit in tube amplifiers, a magnetic head, on playback of a "flat" recording and assuming no losses, exhibits a rising voltage characteristic with increasing frequency at a 6 db-per-octave rate. By contrast, in the transistor amplifier, the 1500-ohm input impedance of the first grounded emitter stage matches the 0.5 henry head at 300 cps. This indicates that the current induced in the head flowing in the X-1 base will have a flat frequency characteristic above, and a 6 db-per-octave rolloff below 300 cps. Consequently, by choosing the head impedance properly, it is possible, when coupling to a transistor input circuit, to eliminate low-frequency equalization on playback entirely. However, choice of too high a tape-head impedance will result in an unfavorable noise figure at the high audio frequencies. The 0.5 henry head proved to be a good compromise between low-frequency equalization and high-frequency noise. For the 0.5 henry head, the equalization employed on playback is shown in Fig. 3. The measurements indicate that junction transistors in general have lower noise when operated at a low-current (<1 ma) and low-voltage (<6 volts)

* Presented at the Sixth Annual Convention of the Audio Engineering Society, New York, October 14–16, 1954.
† RCA Engineering Products Division.

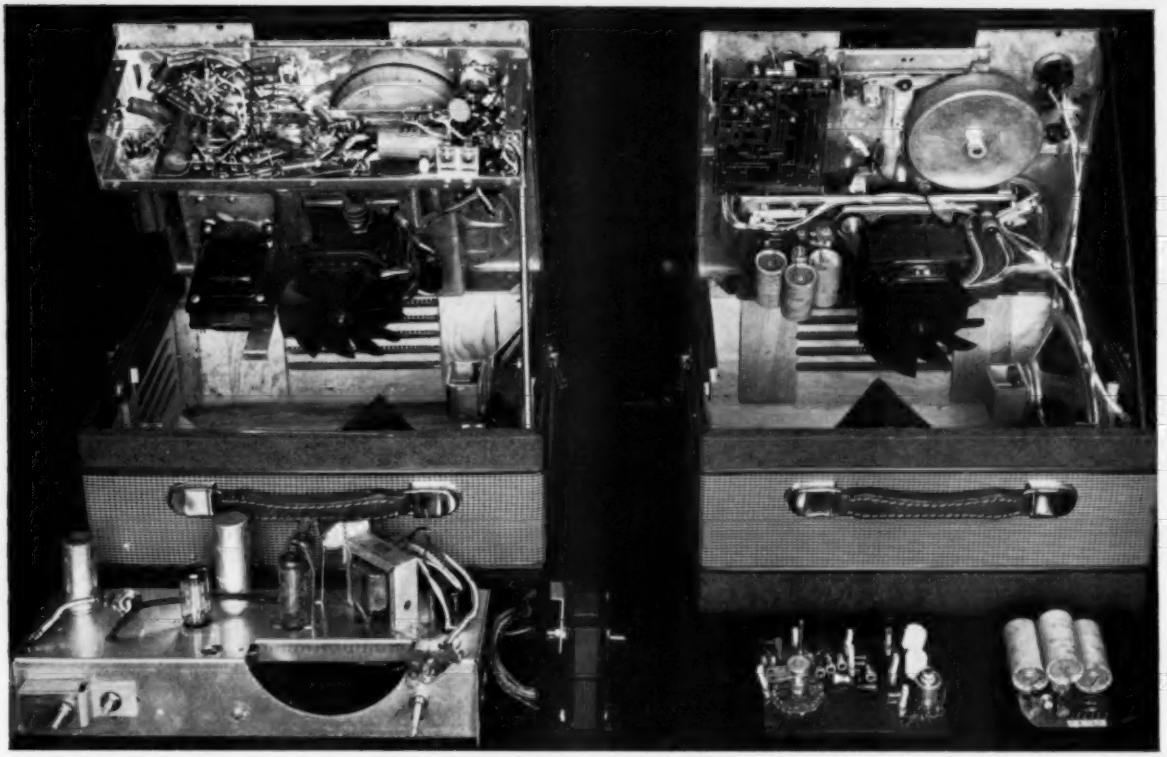

FIG. 1. Left, inside view of a tape recorder with a tube-powered amplifier. Right, inside view of the experimental tape recorder powered with transistors.

collector operating point, and this data has been used in the design of the first amplifier stage.

Using a standard red-oxide tape recorded with a signal representing 3% distortion at 400 cps as a reference level, the signal-to-noise ratio with a 10 db noise-figure input transistor was 60 db. This noise figure represents the playback amplifier alone and does not include hum pickup in the head and noise introduced on the tape during the recording process. Means for minimizing these last two types of noise are known in the magnetic-recording art and are beyond the scope of this paper. The absence of conventional heater wiring, along with the inherent low impedances associated with transistor circuitry, allows an easier and less costly solution of some noise problems common in high-gain audio amplifiers employing vacuum tubes.

Transistors X-1, X-2, X-3, and X-4 are employed as grounded-emitter class A amplifiers on playback principally because the grounded-emitter connection generally offers higher power-gain capabilities than either the grounded-base or grounded-collector connections.

Two dc feedback paths, one from collector to base and another in the emitter circuit, provide for temperature stabilization and for variations among transistors. In addition, the collector-to-base resistance establishes the correct bias for the class A operating point.

The playback amplifier has a total power gain from input to 1 watt output of 115 db, including a 12-db gain reserve at 1000 cps. No microphonic tendencies were noted with this high gain.

BIAS OSCILLATOR AND RECORD AMPLIFIER

During recording, the first transistor, X-1, is switched from an amplifier to a 50-kc tuned collector oscillator.

The oscillator supplies bias power only. A permanent-magnet head is used for erasing. When power transistors having improved high-frequency characteristics are available, an oscillator having sufficient power for both erase and bias functions will be entirely possible. The oscillator voltage is stepped up by a factor of 7 to the 90 volts needed for the record head by the oscillator coil, L-1, which has a secondary winding of 2200 turns.

On recording, the head in series with the oscillator secondary is fed audio frequencies at constant current through the 56,000 ohm resistor, R-20. C-12 in parallel with R-20,

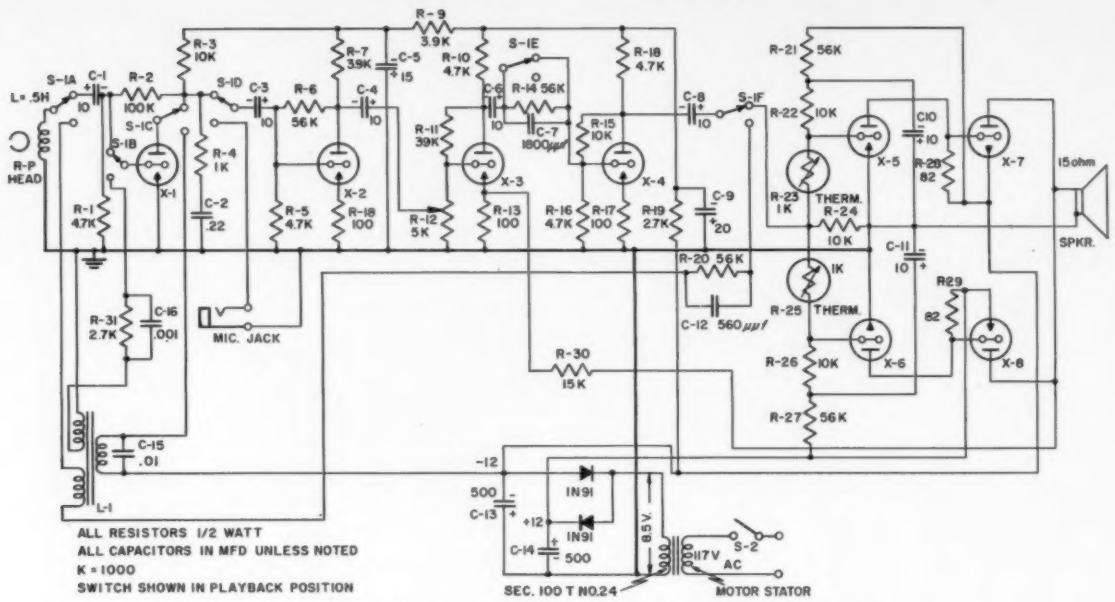

FIG. 2. Schematic circuit diagram of the experimental transistorized tape recorder.

along with the C-7, R-14 parallel network, together effect the pre-emphasis shown in Fig. 3.

The overall record-playback response curve is shown in Fig. 4. Bias and audio currents used were 600 and 60 microamp respectively.

The record-level indicator proved to be one of the most difficult problems to solve. Unlike the common practice of using neon glow lamps for indicators in tube recorders, nowhere in the transistor circuit are the audio voltages high enough to fire the neon bulbs. It appears at present that a satisfactory solution would be to use a meter for record-level indication.

POWER SUPPLY

The low power required for transistor circuits permits a unique power supply to be used in this recorder. The transformer for the power supply was provided by adding 100 turns of no. 24 wire in a vacant slot on the motor-stator core. This simple modification provides line-isolated power and saves the cost and bulk of a 3-lb power transformer. In addition, the elimination of the power transformer reduces the magnetic field sources to the motor only, and simplifies the induced hum problem at the playback head.

Two 1N91 power geranium diodes and two 500 mfd capacitors are used to filter the positive and negative power supplies. This diode, with its 1-ohm forward resistance, is necessary to achieve good regulation since the collector current in the class B output stage varies from 10 ma to 200 ma on audio peaks.

The total power required for the recorder varies from .25 to 1.5 watts depending on the audio output. Thus, this amplifier together with a spring wound or battery powered motor would make a very practical portable recorder. Transistors require no warm-up time, making the recorder usable instantly.

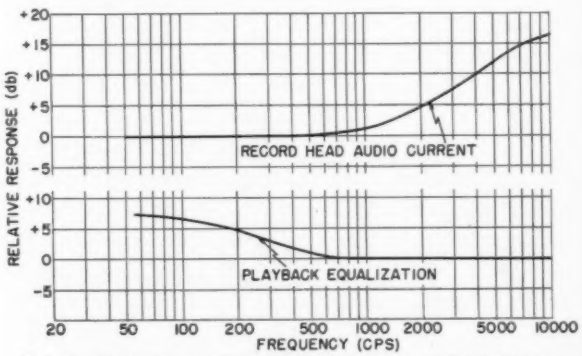

FIG. 3. Recording current versus frequency- and playback-response curve.

OUTPUT STAGE

The output stage consisting of two direct-coupled complementary-symmetry class B grounded emitter stages is similar to a circuit described previously,[1] except that the feedback circuit has been changed and also temperature compensation has been added.

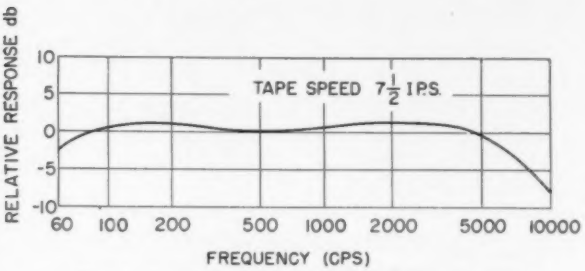

FIG. 4. Overall record-playback frequency response.

Complementary symmetry is a unique property of transistors where, depending on the construction of the transistor, conduction in the collector-emitter circuit may be either positive or negative. Thus when NPN and PNP (positive and negative conduction respectively) transistors are connected in parallel, a single-ended input signal will provide push-pull output. This interesting circuit configuration permits direct coupling to the load, eliminating the need for an output transformer and a phase inverter.

Transistors are sensitive to temperature rise requiring that dissipation be kept as low as possible, and this fact makes class B operation very desirable in obtaining maximum power output from transistor circuits. Transistors in class B operation approach the theoretical maximum efficiency of audio to dc input. To avoid crossover distortion, the input class B drivers are biased to cause approximately 5 ma collector current to flow in each output transistor. The crossover distortion is caused by the nonlinearity of the base diode near cutoff. The resistor network, comprising resistors R-21 to R-27, establishes the operating point of the class B stages. R-23 and R-25 are thermistors whose resistance decreases with temperature, thus reducing the bias to compensate the output stage for increases in ambient temperature. Sixteen db of feedback is applied from the load resistance to the emitter resistance of X-3 to limit harmonic distortion to 2%. Distortion versus power-output characteristics are shown in Fig. 5.

As explained in the introduction, the transistorized tape recorder was developed as an experimental model to demonstrate the advantages to be gained through the use of transistors in certain audio circuits. No plans, at present, include a commercial model of this device.

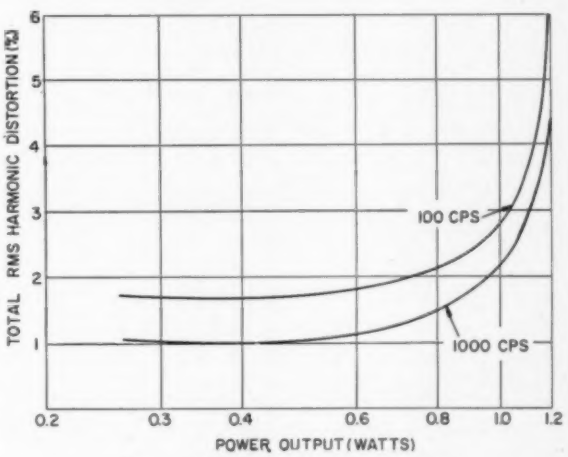

FIG. 5. Distortion versus power output.

[1] R. D. Lohman, "Complementary-Symmetry Transistor Circuits," *Electronics*, 140 (September 1953).

Magnetic Pickups and Proper Playback Equalization*

WALTER O. STANTON†
Pickering & Co., Inc., Oceanside, N. Y.

The author discusses the basic principles of magnetic disc recording and the theory of precise playback equalization, particularly with respect to magnetic pickups.

THE ADVENT of flat-frequency-response electrostatic transducers, covering most or all of the audio spectrum, requires a re-examination of current thought about equalization to determine how we can best meet more stringent standards of reproduction. In the absence of the masking effect of cone breakup and resonances, the electrostatic transducer quickly shows up any unbalance and distortion which happen to be present in other components of the system.

A review of present-day theory and practice in cartridge equalization will help establish the type of pickup which is needed for top quality in reproduction. The conclusions can be helpful to both user and equipment manufacturer, particularly to the latter, since he should be certain, at all times, that his product is proper for its intended purpose.

A discussion of this subject is timely, not only because of the introduction of electrostatic speakers, but also because we are hearing more and more often that accurate playback compensation is unimportant. There is a growing tendency in some areas to lower the standards for good reproduction and ignore the principles which are the foundations of modern audio practice. In fact, these good principles to which I refer are also the underpinnings of high-quality audio as an industry, the industry upon which many of us depend for more than entertainment. The growth of this field has resulted from a widespread public demand for better sound. Lowering performance standards is retrogressive and not in the best interests of the industry. There is only one way to assure continuing growth and prosperity and that is by a continual upgrading of requirements.

In general, the retrogressive argument seems to be based upon two popular misconceptions:

1. That modern recordings are "essentially" constant amplitude and can be reproduced adequately by constant-amplitude pickups having nonlinear mechanical response which departs as much as 3, 4, or 5 db from the ideal response.

2. That non-uniform pickup response, with deviations of 3, 4, or even 5 db throughout the entire audio band, are quite acceptable as "high-quality" pickups and further, that high-frequency deviations of 10 or more db are also acceptable.

THE RIAA STANDARD RECORDING CHARACTERISTIC

To establish a rigorous engineering viewpoint, I would like to refer to the RIAA‡ Standard Recording Characteristic as published by that Association. The Standard recording curve is actually the algebraic sum in db of three admittance curves shown in Fig. 1 and defined as follows:

1. A parallel L/R network having a time constant of 3180 microsec.
2. A series RC network having a time constant of 318 microsec.
3. A parallel RC network having a time constant of 75 microsec.

The curves of Fig. 1, added together as shown in Fig. 2, define the Standard recording-channel response to a constant applied voltage and also the *velocity* response of a modern feedback-type magnetic cutter when driven by a Standard channel.

With this curve of the Standard characteristic graphically set forth, we can determine just how closely it comes to being a constant-amplitude characteristic.

Recording at constant mechanical amplitude would re-

* Presented at the Seventh Annual Convention of the Audio Engineering Society, New York, October 12–15, 1955.
† President.
‡ Recording Industry Association of America.

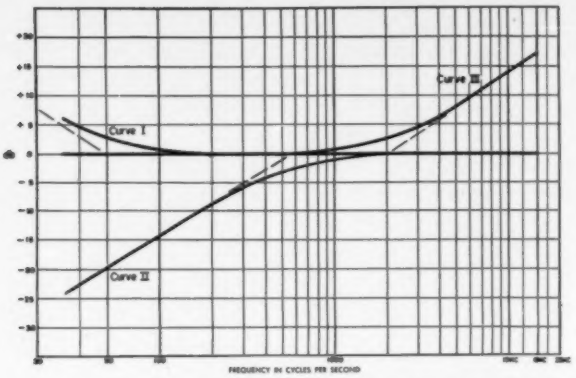

FIG. 1. The three admittance curves which, when algebraically added, yield the RIAA Standard Recording Characteristic shown in Fig. 2.

quire that the cutter velocity have a positive 6-db-per-octave slope, as shown in Fig. 3.

If we superimpose Fig. 3 on Fig. 2 we can make a direct comparison to the bass and treble slopes of the RIAA curve. This comparison is shown in Fig. 4.

From Fig. 4 we can measure velocity differences and easily construct the amplitude response of the channel defined by Fig. 2. This is done in Fig. 5.

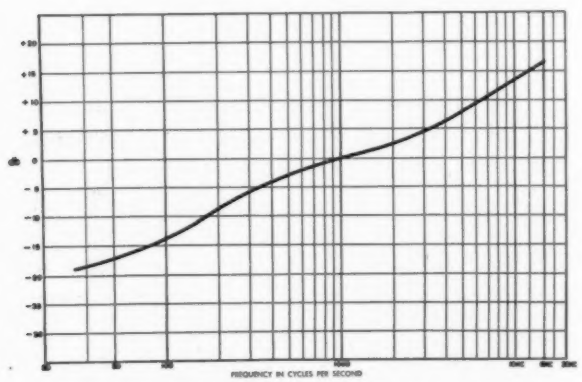

FIG. 2. The RIAA Standard Recording Characteristic.

This curve shows that the RIAA Standard recording characteristic departs widely from a constant-amplitude curve. Large differences between the two characteristics occur in the important fundamental spectrum of the musical scale.

Since Figs. 2 and 5 define the RIAA Standard curve—velocity-wise and amplitude-wise, respectively—it is obvious that any pickup device, whether in the one sense or the other, must be equalized in order to restore the original balance among the various recorded frequencies. This fact is well known in technical circles, but so much to the contrary has been published lately that it seems necessary to reaffirm these basic precepts, particularly as they apply to the misconceptions about the "essentially" constant-amplitude character of modern recordings.

Loosely worded descriptions of recording curves have led directly to another popular notion, which is that uneven pickup response caused by inaccurate equalization of the order of 3, 4, or 5 db is still "essentially" flat. One of the most specious arguments used to support this view is that, since loudspeakers are not flat within *10* db, what are 3 or 4

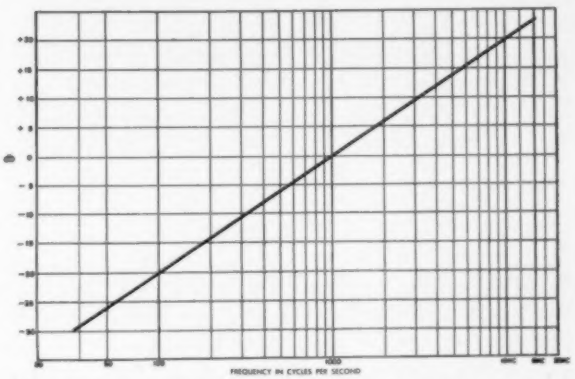

FIG. 3. If the recording is made at constant mechanical amplitude, the cutter velocity must have a positive 6-db-per-octave slope, as shown above.

db among friends? The point that is overlooked in such a statement is that dynamic speakers "break up," an action quite different from that of pickups, and radiate sharply varying amounts of acoustical power at closely spaced intervals in the frequency spectrum. This property gives rise to the familiar sawtooth profile of the speaker response curve.

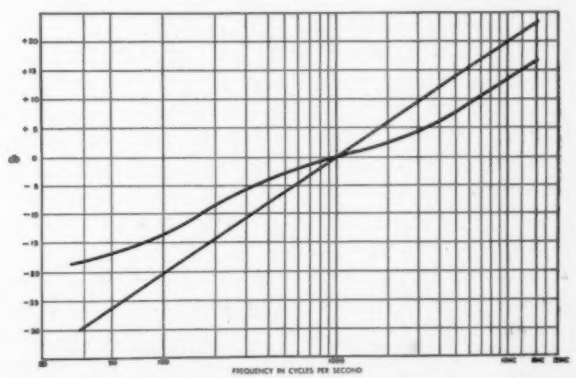

FIG. 4. Comparison of the bass and treble slopes, respectively, of the RIAA curve and of the characteristic of Fig. 3, i.e., one exhibiting a 6-db-per-octave slope.

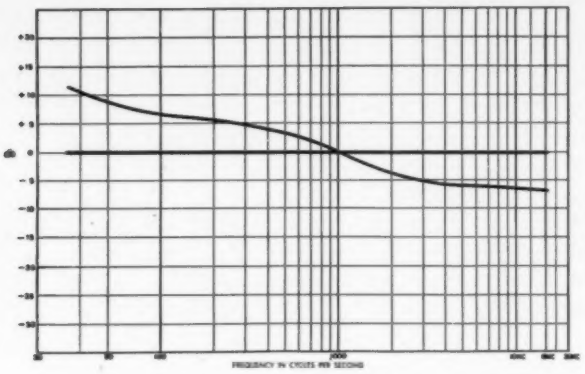

FIG. 5. The amplitude response of the channel defined by Fig. 2, showing that the RIAA Standard characteristic is far from flat on a constant amplitude basis.

The closely spaced sawtooth response of a speaker seems to have an averaging effect which can be tolerated musically, if the power delivered to it is in proper balance.

Pickups, on the other hand, if incorrectly equalized, will show uneven response over much wider segments of the audio spectrum, with the result that the power delivered to the speaker can be out of balance by a factor of 2, 3, or more. If this occurs in the important middle frequencies, as is often the case, the effect is roughly comparable to changing the crossover point by several hundred cycles.

In addition to the acceptance of wide variation in low- and middle-frequency response, there is an even greater latitude unjustifiably allowed for pickups in the octave between 10 kc and 20 kc. Almost every important record company is now releasing discs with wide-range material requiring reproduction in this part of the band. Recent measurements have revealed that many selections have full reference level above 10 kc. Of those pickups which respond in this octave, many have serious peaks amounting to 10 or 15 db. Since normal equalization will not compensate for these peaks, strict attention must be paid to their effect on the power-handling capacity of the system. This is particularly significant, because it is in this region that the average system has the least ability to handle overload.

The discussion up to this point has been an attempt to stress the importance of an accurate playback response characteristic as a function of the equalized pickup. Since some types of pickups are equalized mechanically at the stylus and others compensated electrically, it is necessary to review the several approaches in order to establish the relative advantages of each type.

Broadly speaking, there are two types of phonograph pickups, the relatively high-output, so-called constant-amplitude types and the low-output velocity pickups. The former type embraces the crystal or ceramic group of pickups and the latter, the magnetic group. In general, the ceramic or crystal pickups are equalized mechanically at the stylus, whereas the magnetic pickups rely on electrical networks to compensate for recording characteristics.

Referring again to the RIAA Standard specification as typical of recording curves, it is important to recognize that it applies to cutters of the magnetic type. Playback curves as defined by both the RIAA and the AES imply the use of magnetic pickup devices. This is so because it is generally acknowledged that only a magnetic pickup can trace an exact replica of the cutter response to the original program of music or speech.

THE AES PLAYBACK CURVE

The AES playback curve is defined as the algebraic sum of three separate impedances:

1. A parallel combination of a resistor and capacitor having a time constant of 75 microsec. This curve provides high-frequency rolloff (–3 db at 2120 cps and –13.7 db at 10,000 cps).
2. A series combination of a resistor and capacitor having a time constant of 318 microsec. This curve provides low-frequncy boost, rising at the rate of 6 db per octave below a 500-cps crossover point (+3 db at 500 cps and +20 db at 50 cps).
3. A parallel combination of a resistor and inductor having a time constant of 3180 microsec. This curve provides a very low low-frequency rolloff, resulting in a departure of 3 db at 50 cps from the 6-db-per-octave slope of curve 2.

Thus it is seen that the identical network must be used to restore the recorded program to its original balance. The block diagram of Fig. 6 serves to illustrate this point and also serves to indicate the high degree of accuracy with which the playback should be controlled for precise balance.

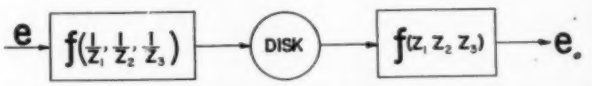

FIG. 6. A block diagram illustrating the high degree of accuracy with which the playback should be controlled for precise balance.

BASIC EQUALIZATION METHODS COMPARED

So far, the technical remarks have been theoretical. Now let us examine the ways in which playback equalization is achieved in the two kinds of pickups.

Considering first the so called amplitude-sensitive devices —utilizing crystal or ceramic elements—we find that com-

pensation is usually applied in the form of nonlinear impedance directly coupled to the stylus. At least two methods are in common use.

The first method, illustrated in Fig. 7, employs a combined viscous and stiffness coupling between the stylus and the generating element. This provides a driving force at the generator which is the sum of velocity and displacement factors.

The second method, shown in Fig. 8, employs a stiffness coupling between generator and stylus. Both systems utilize resonances in the generator to provide crossover and high-frequency rolloff.

Thus, the response curves of pickups so constructed are generally characterized by resonance peaks or bumps in the middle and middle-high-frequency range. Further, the rate of high-frequency rolloff varies according to the Q of the resonant elements. Because the generating element is part of a mechanically resonant circuit, the amplitude and phase characteristics of its motion differ from the stylus movement. In addition, none of the elements of the mechanical impedance network are in a *pure* form: damping has mass and stiffness, stiffness has distributed mass, etc.

MOVING-COIL AND MOVING-IRON MAGNETIC PICKUPS

Of the magnetic pickups there are two types in general use—the moving-coil type and the moving-iron type. The virtue of the moving-iron type is that the dynamic mass can be reduced to a value so low that changes in the mechanical characteristic are completely negligible throughout the audible spectrum and, indeed, to points beyond both ends of the spectrum. In other words, with a highly refined moving-iron unit having flat response to 30 or 40 kc, there is practically no "pickup coloration" of the reproduced sound. Admittedly, this has not always been so, but it is true now with at least one pickup commercially available.

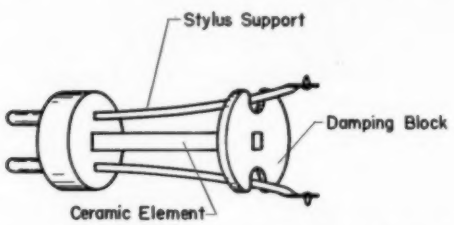

FIG. 7. An amplitude-sensitive pickup. Compensation is applied here in the form of nonlinear impedance directly coupled to the stylus. The particular method used here employs a combined viscous and stiffness coupling between the stylus and the generating element. This system utilizes resonances in the generator to provide crossover and high-frequency rolloff.

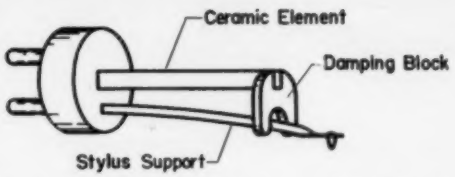

FIG. 8. A system employing a stiffness coupling between the generator and the stylus. Here, too, resonances in the generator provide crossover and high-frequency rolloff.

The advantages of this kind of pickup behavior are obvious. The record has control over the pickup throughout the entire audio spectrum. Also, the generating element can be located physically within a *few thousandths* of an inch from the record. Hence, distortion due to mechanical linkages or impedances between stylus and generator is virtually absent.

As a result of this design approach, the pickup recovers a signal which accurately corresponds to the magnetic cutter's motion at the time of recording. This accurately reproduced signal can then be equalized with an electrical network having the same constants as the recording network within very narrow tolerances.

The importance of this fact is that the error between recording and playback can be reduced to an almost insignificant value and our approach to perfect fidelity made that much closer.

A Co-ordinated Church Audio-Visual System*

CLYDE R. KEITH†

The increasing use of amplifying systems, motion-picture projectors, tape recorders, and other audio-visual equipment in churches brings a demand for better and more convenient use of these facilities. The advantages of interconnections between the different pieces of equipment, permanent wiring, and semi-permanent projection facilities are pointed out. A system embodying such facilities is described and some general suggestions made for designing special audio-visual systems.

WHILE the use of projected pictures and electrically reproduced sound in churches has increased greatly in the last ten years, such equipment has, in most cases, been utilized in the form of separate units connected by cords as the occasion required. It is apparent, however, that many advantages can be achieved by a system designed to provide permanent interconnections between various locations and pieces of equipment, thereby eliminating cords from the audience area and reducing setup time. A description of such a system, designed to meet the requirements of a particular church, may provide some ideas that may help meet the specific requirements of other churches or educational institutions.

Since the system was planned and installed at the time when a new chapel and group of church school rooms were being built, it was possible to provide permanent concealed wiring and a "projection booth" at minimum cost while new walls were being built and other wiring installed.

This system was designed to provide the following facilities:

1. Sound transmission from the sanctuary to each of two other rooms for overflow meetings on special occasions.
2. Sound transmission from the sanctuary to the vestibules and chapel without requiring a special operator.
3. The playing of disc records through the amplifier system.
4. The playing of a tape recorder through the amplifier system.
5. The making of tape recordings from the amplifier system.
6. Connection of a motion-picture projector to built-in loudspeakers in chapel.
7. Elimination of projector noise when motion pictures are shown in chapel.

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OVERFLOW SOUND SYSTEM

This portion of the system is used on special occasions, such as Christmas and Easter, when a part of the congregation must be seated in another room.

Three low-impedance (50-ohm), dynamic microphones are used for sound pickup in the sanctuary. Two are mounted permanently, one on the pulpit and one on the lectern; the third is connected to a floor outlet in the choir section. The mixer, shown in Fig. 1, includes 4 manually operated volume controls (P_1, P_2, P_3, and P_4,) 3 of which are connected through the back contacts of relay K_2. This allows for a *fourth* microphone, which may be installed at a future date in the rear of the sanctuary for processionals. A low-level mixer was used to avoid the expense of individual microphone preamplifiers, but this required the use of the special low-noise preamplifier shown in Fig. 1. In this cathode-follower amplifier, all the gain is furnished by the 14:200,000-ohm input transformer. This raises the voltage about 40 db before it can be affected by tube hiss or microphonics.

Following the mixer are a conventional preamplifier and a 50-watt power amplifier. While this amount of power is more than can be handled by any of the remote loudspeakers, it permits the convenience of local volume control without overloading the amplifier. Each of the volume controls consists of a step-type attenuator located in the rear of the room and is operated by an usher for final volume adjustment. Portable loudspeakers are plugged into wall outlets when required.

Also provided are a VU meter, a monitor loudspeaker, and switches for connections to the various loudspeaker circuits. The loudspeakers are each connected to the amplifier output through 500:8-ohm transformers. Since the amplifier output impedance is stabilized at a comparatively low value by feedback, the volume in one loudspeaker is not appreciably affected by switching others on or off.

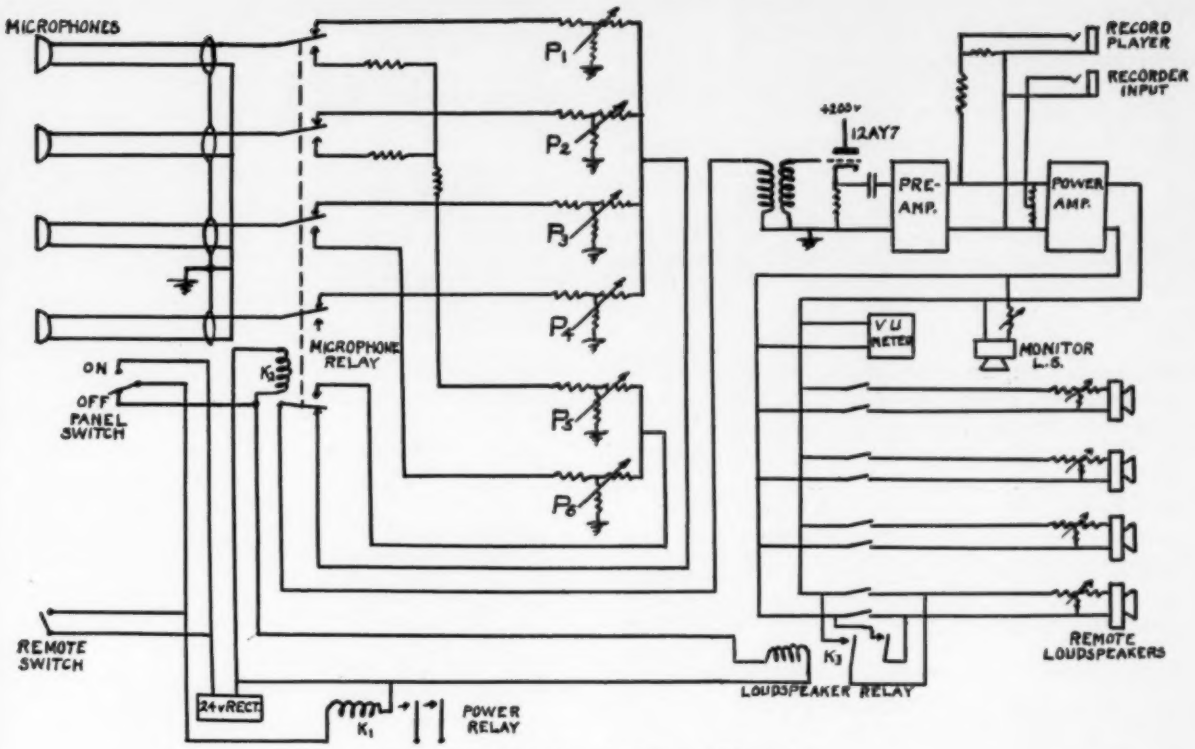

FIG. 1. Simplified schematic of the amplifier system.

The mixer and amplifier equipment are located in a cabinet in one of the church school rooms adjacent to the new chapel. As shown in Fig. 2, the mixer and loudspeaker controls are located behind a front panel which opens similar to a writing desk. The same cabinet is used for mounting the motion-picture projector and includes storage space in the central portion of the cabinet. The smaller cabinet on the left contains the amplifiers as well as the monitor loudspeaker. Connections to microphones are made by shielded pairs in conduit, while standard three-conductor BX cables are used for loudspeaker lines.

VESTIBULE SOUND SYSTEM

Since this portion of the system is used every Sunday, it is arranged to be turned on and off by remote control from a switch in the sanctuary light-control cabinet. In order to be sure that the microphone volume controls are not set at the wrong positions because the last operator forgot to return them to normal, the remote switch operates a relay, K_2 of Fig. 1. This connects the pulpit and lectern microphones through pre-set "screwdriver" volume controls, P_5 and P_6. A second relay, K_3, connects the vestibule loudspeakers to the amplifier output independently of loudspeaker switches and a third relay, K_1, turns on the power. This arrangement has proven reliable and practically foolproof.

PLAYING DISC OR TAPE RECORDINGS OVER THE SOUND SYSTEM

Input jacks are provided for connecting either a disc player or tape playback to the amplifier system. Resistors are provided to terminate the record player and amplifier input properly, as shown in Fig. 1. Since this connection is made at a point in the amplifier system at which the gain is fixed, volume is adjusted by means of the volume control on the record player. It was necessary to provide an appropriate jack in the record player for connecting to its output and disconnecting its loudspeaker, but the tape recorder had already been provided with this facility when purchased.

MAKING MAGNETIC TAPE RECORDINGS

When it is desired to record the sound picked up by the

microphones, it is only necessary to connect the "radio" input of the tape recorder to a jack bridged across the power-amplifier input. This connection is made through a high resistance (25,000 ohms) so that no failure or wrong connection of the tape recorder will affect the transmission of sound to the loudspeakers.

MOTION-PICTURE SOUND SYSTEM

While the motion-picture projector is a standard 16-mm portable machine and is also used in locations other than the chapel, the special facilities provided for showing pictures in the chapel give such superior results that most pictures are shown there. It was originally planned to connect the motion-picture amplifier to one of the sound-system volume controls through a suitable attenuator, but this turned out to be unsatisfactory for several reasons. For one thing, it would require the motion-picture operator to learn how to operate the sound system, with additional possibilities for misoperation. Also, the great difference in level between the projector output and the sound-system input brought in difficulties due to "longitudinals" or ac hum, which was not attenuated as much as the sound current. Consequently, the projector output was connected to an 8:500 ohm transformer which is connected to the chapel loudspeaker line. This connection is made through a multiple-contact jack so that when the cord from the projector is removed, the sound-system amplifier is automatically connected to the chapel loudspeakers. These loudspeakers are installed in the ceiling near the screen and are similar to those used for wired-music systems. While these 8-in. loudspeakers are adequate for most sound films, additional low-frequency response is obtained, when desired, by means of a 12-in. speaker in a portable cabinet connected to an outlet behind the screen. The local volume control is located at the rear of the room, so that volume adjustment may be made without distracting the audience.

OTHER MOTION-PICTURE PROJECTION FEATURES

Another important factor in improving the projection of 16-mm motion pictures was the elimination of the projector noise from the audience area. Although it was not practical to provide a projection booth, the same effect was obtained by mounting the projector on a cabinet inside a classroom at the rear of the chapel (Fig. 2). The cabinet is high enough to keep the projected light beam above the heads of persons who come in after the picture has started. A small, fixed, plate-glass window is provided for the projection beam and a hinged window for the operator to view the screen. This window may be opened so that the operator may hear the preliminary portions of the meeting; the window is, of course, closed while the picture is being projected. The monitor loudspeaker allows the operator to judge sound quality even though he cannot hear the chapel loudspeakers. Since the projector is mounted too high to be operated while the operator is standing on the floor, a platform is built into the cabinet. This slides into the cabinet when not in use. As the mixer is not ordinarily used while projecting a picture, the outside panel is closed at such times in order not to interfere with the operator, who is standing on the platform.

FIG. 2. At the left, the cabinet housing the amplifier and monitor loudspeaker; at the right, the combined mixer, storage cabinet, and projector stand.

Power outlets for projector, tape recorder, etc., are provided on the left side of the projector stand (Fig. 2), as are the jacks for record-player and tape-recorder connections.

A further convenience is obtained by having the chapel lights wired so that they can be controlled by the motion-picture operator. Three-way switches are used so that they may also be controlled at convenient places in the chapel when pictures are not being shown. In addition to the exit lights, a very small light is located at the rear to enable latecomers to see which seats are not occupied.

The screen is a standard wall-mounted roller type, mounted behind a cornice or valence, so that it is not visible when not in use. It is square, rather than of the usual 4:3 ratio, to permit showing slides in which the long direction is vertical as well as slides in which the long direction is horizontal.

Sound filmstrips also may be shown in the chapel by

mounting the filmstrip projector beside, or in place of, the motion-picture projector and by connecting the record player through the amplifier system to the loudspeakers.

An effective presentation is obtained by having the room darkened and a suitable slide projected on the screen while the audience is arriving. Music from the record player also helps to establish an appropriate atmosphere. When the motion picture is started, the sound from the record player is faded out and the film sound faded in. At the end of the film, additional music from the record player or tape recorder may be used to maintain the mood while the audience is dispersing. It is felt that the elimination of distracting factors and the addition of a certain amount of "atmosphere" definitely helps the film convey the desired message.

SUGGESTIONS FOR DESIGNING SPECIAL AUDIO-VISUAL SYSTEMS

A few suggestions may be in order for the benefit of persons who would like to plan an audio-visual system which will meet the specific requirements of a particular church. The first step is to decide on the facilities which are most likely to be wanted over a period of the next five to ten years. In addition to those provided in the system described above, some of the following might be desirable: projection of sound pictures in the church auditorium, sound reinforcement in the auditorium, distribution of sound to church school rooms.

The next step is to secure the services of a qualified audio engineer to design the system and specify the equipment. He should also consult with the architect, in the case of remodeling or the erection of a new building, at a time far enough ahead of the start of construction so that the necessary audio-visual facilities can be included in the architect's plans. The audio engineer should also check with the building contractor to see that the wiring and equipment are properly installed, and, finally, should test the completed system to see that it does what it is intended to do.

One of the important considerations in any audio-visual system is that adequate provision be made for darkening any room where slides or motion pictures are to be shown. So-called "daylight" projection is seldom satisfactory and is no substitute for proper light control. Practical methods for darkening rooms are described in several recent publications.[1,2]

Sound reinforcement in acoustically defective auditoriums may present many difficult problems and should not be attempted without the advice of a competent audio engineer. Furthermore, no amplifier and loudspeaker system can be expected to overcome all difficulties due to faulty design or poor acoustical treatment of an auditorium.

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[1] *Planning Schools for Use of Audio-Visual Materials, No. 1, Classrooms, and No. 2, Auditoriums,* Department of Audio-Visual Instruction of the National Education Association, 1201 Sixteenth St. N. W., Washington, D.C. Price $1.00 each.

[2] *The Architect's Manual of Engineered Sound Systems,* Radio Corporation of America, Camden, N. J.

Some Design Criteria For Magnetic Tape*

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The characteristics of a magnetic-recording system depend, among other things, upon the magnetic properties of the recording tape and the intensity of the supersonic recording bias. In general, increasing the bias signal results in an increase in the depth of the recording into the tape and poorer response at short wavelengths. Therefore, the coating thickness and the bias intensity are related in their effect upon overall frequency response.

Tape coatings having high magnetic remanence properties are superior (especially at long wavelengths) to conventional coatings.

Orientation of the magnetic particles in the tape coating is shown to be beneficial. Consideration of these and other basic principles facilitates the design of tapes having optimum properties for specific recording applications.

CALCULATION of the frequency response of a magnetic recording system from the physical constants of the tape and transducer heads has received much attention in the literature. For instance, it is now possible to compare magnetic-tape reproducing systems and if the reproduce heads are carefully constructed and measured, to predict with some accuracy the relative response of a recorded tape on any such system.

Indeed, by applying appropriate corrections for electrical losses in the reproduce head and by taking into account the fact that the air gap of the head and the spacing between the head and the tape are finite (though they may be very small), it is possible to define and measure the so-called "surface induction" of a recorded tape.[1,2]

The term, surface induction, incidentally, defines the actual field intensity existing at the boundary surface of the tape. (It should be borne in mind that this intensity may change somewhat when the tape is placed in contact with the highly permeable core of a reproduce head.) Surface induction is also a measure of the magnetic induction actually recorded within the tape.

For obvious reasons, the aforementioned concepts and techniques are of inestimable value in standardizing reproducing systems for interchange of magnetic tapes. This paper, however, will deal with the problem of system performance *in terms of the characteristics of the recording process and of the tape itself*. In other words, we shall not be concerned with the reproducing *system*, per se, but only with those factors (exclusive of equalization) which contribute to the surface induction of the recorded tape.

In predicting the overall performance of a system, nonlinearity and hysteresis effects in the magnetizable tape coating present problems which are particularly difficult. These difficulties are only partly alleviated by the use of supersonic bias during recording. Until more refined mathematical methods are available, the treatment of this phase of the problem must be largely empirical. It is possible, however, to explore the effects of various tape parameters in orderly fashion and to formulate some "rules of thumb" regarding the design of magnetic recording tapes.

MODEL OF THE RECORDING PROCESS

Previous papers dealing with the recording process[3,4] have described experiments in which the magnetic material of the

* Presented at the Seventh Annual Convention of the Audio Engineering Society, New York, October 12–15, 1955.

† Research and Development Manager, Magnetic Products Division.

[1] E. D. Daniel, "The Influence of Some Head and Tape Constants on the Signal Recorded on a Magnetic Tape," *Proc. I.R.E.*, **100**, Pt. 3, 168–175 (May 1953).

[2] W. K. Westmijze, "Studies on Magnetic Recording," *Philips Research Reporter*, **8**, 148–157 (April 1953); 161–183 (June 1953); 245–269 (August 1953); 343–366 (October 1953).

[3] W. W. Wetzel, "Review of the Present Status of Magnetic Recording Theory," *Audio Eng.*, **31**, 14–17, 39 (November 1947); **31**, 12–16, 37 (December 1947); **32**, 26–30, 46–47 (January 1948).

[4] O. W. Muckenhirn, "Recording Demagnetization in Magnetic-Tape Recording," *Proc. I.R.E.*, **39**, 891–897 (August 1951).

coating was subjected to oscillating fields designed to simulate those actually encountered by the tape in passing near the record gap. While these experiments yielded much insight into the nature of the recording process, they failed to explain a number of observed recording phenomena, such as:

1. The performance of a recording system (neglecting losses in the core of the recording head) is unaffected by the frequency of the bias field as long as its frequency is sufficiently high.

2. The performance of a magnetic tape is greatly influenced by the thickness of the magnetic layer.

3. The recording process (unlike the reproducing process) is remarkably tolerant of gap length. Wavelengths much shorter than the gap length may be recorded with good efficiency.

It is therefore convenient to introduce a simplified model of the recording process, so that the effects of tape properties and recording conditions may be studied in broad outline. Since the length of the recording gap does not seem in practice to be critical, the gap may be represented by an infinitesimal slit; in that case, the flux lines become arcs of circles in a two-dimensional plot as shown in Fig. 1, and the field intensity varies inversely as the distance from the slit. (The assumption of an infinitesimal recording slit is not essential to the explanation of the recording process. The assumption is made for convenience in illustrating the general configuration of the fields involved.) It will be assumed also, that the permeability of the tape coating is unity, so that the shape of these fields is not greatly altered by the proximity of the tape.

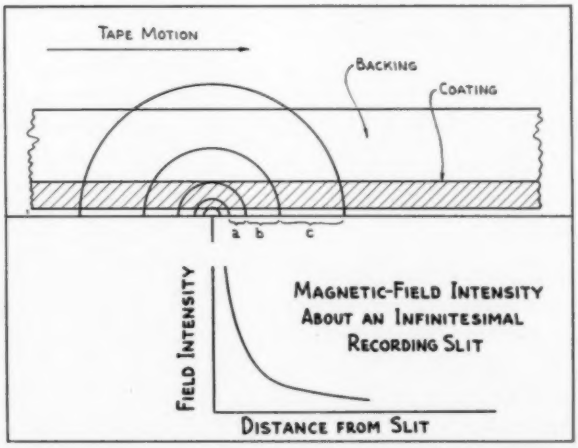

FIG. 1. A simplified model of the magnetic recording process. (The assumption of an infinitesimal recording slit is not essential, incidentally, to the explanation of the recording process.) It is assumed that the permeability of the tape coating is unity. The plot given above takes into account only the geometric factors influencing the field intensity.

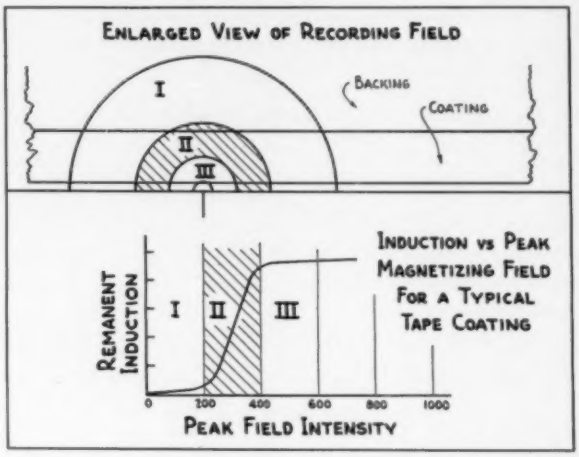

FIG. 2. An enlarged view of the recording fields of the recording-process model of Fig. 1. Also, a static remanent-induction curve for a typical tape coating.

The plot of Fig. 1 takes into consideration only the geometric factors influencing the field intensity: It must be remembered that the tape is in motion, and also that the field is *time variant* in response to the audio and bias signals energizing the head. In audio recording, the maximum audio signal in the recording head seldom exceeds one-tenth of the bias signal. Therefore, in considering the peak intensity to which the field may rise, we are primarily concerned with the bias signal. Fig. 1 also shows that the field intensity varies greatly throughout the thickness of the tape, and that the direction of the field is horizontal directly above the gap only. Therefore, we must expect that elements of the tape nearest the surface will probably be saturated during passage through the intense part of the field and, moreover, will encounter strong vertical fields in departing from the gap.

Experiments have shown that the behavior of a practical recording head with a finite gap is not basically different from this model.

Leaving the subject of the recording fields for the moment, we turn now to the properties of the magnetic tape coating. Figure 2 shows an enlarged view of the recording fields as well as a static remanent-induction curve for a typical tape coating. It is apparent that the remanent induction established in this tape coating rises very abruptly over the narrow range of field intensities from 200 to 400 oersteds. It may be said that the tape coating represented by Fig. 2 is not appreciably affected by fields of less than 200 oersteds;

this fact is further corroborated by the observation that a 200-oersted ac field causes no appreciable erasure of a recorded signal. On the other hand, this same coating is—for all practical purposes—saturated in a field of only 400 oersteds, since further increases in field intensity have an insignificant effect upon the ultimate remanence.

Returning now to the recording field plot of Fig. 2, it is possible to divide the region about the slit into three zones corresponding to ranges of field intensity:

Zone I. Too weak to cause recording.
Zone II. Of the correct intensity for recording.
Zone III. Of saturating intensity, for which changes in the signal do not ultimately affect the remanence in the medium.

It follows that the remanent induction in an element of the tape depends almost entirely upon the behavior of the recording signal during the time it is departing through zone II. Therefore, we might expect the remanent signal in the deeper layers of tape to be shifted with respect to that on the surface—due to the curved shape of recording zone II—leading to phase shift between the components. This phase shift undoubtedly causes some reduction in signal amplitude at wavelengths approaching the thickness of the tape. We might also expect a considerable vertical component in the recording, particularly at the surface of the tape, a fact which seems to be borne out by experiments which will be described below.

As far as the direction of magnetization is concerned, it is well established that direction is rather immaterial, particularly for short wavelengths.

Our model of the recording process will now be verified by a series of experiments. Our model will then be used to predict the performance of practical tape constructions.

RECORDING DEPTH AND DEFINITION

The usual method of determining the proper bias signal for a particular recording-tape and machine combination is to record a low-level, low-frequency signal and vary the bias until the maximum intensity of reproduced signal is obtained. A point is reached where further increase in the amplitude of the bias signal is accompanied by a loss in recording sensitivity; it has been found, however, that the audio signal may also be increased in order to restore the output to its original value.

Suppose that both the audio and bias signals are each greatly increased, say, by a factor of 2 or 4. The result of this experiment is given in the following table:

Bias Current (in ma)	Audio Current (in ma, $\lambda = 20$ mils)	Audio Output	Percent Third-Order Distortion
2.3	.14	52.9	1.0
4.6	.28	51.6	1.2
9.2	.56	51.9	1.5

It is apparent from this data that at low frequencies, the efficiency of the recording process is not materially altered by large increases in the recording signals, *as long as both the audio signal and bias are increased proportionally*. This phenomenon is explained in our recording model by a widening of the recording zone, as shown in Fig. 1.

In recording at optimum bias, the recording probably takes place in the region *a*, which is defined by the two indicated flux lines. Doubling the amplitude of the recording signals moves each of these boundaries—which define the region of proper recording intensities—twice as far from the slit, with the result that recording takes place in region *b*. Similarly, when the audio-signal amplitude and the bias amplitude are once again doubled, the recording region will shift to region *c*. Therefore, if the ratio of audio and bias currents is maintained constant, their amplitudes may be increased at will and the recording process will remain essentially the same, *except that it will take place in an advanced portion of the recording field*. Another effect of this bias increase is to reduce the field gradient over the recording range and hence destroy the definition of the system. During the passage of the tape through the expanded recording zone (*b* or *c* of Fig. 1) a high-frequency audio signal may be changed considerably in phase or even reversed in polarity. Thus, the short-wavelength definition of the system is quite sensitive to the amplitude of the recording bias.

It is now possible to examine in detail the effect of the thickness of the magnetic coating on recording properties. It has been shown that very intense fields may be employed in recording low-frequency signals on a magnetic tape with little deleterious effect upon performance. Therefore, it follows that almost any thickness of coating may be fully magnetized at low frequencies, even though the intensity of the recording field changes rapidly with distance from the gap. This is illustrated in Fig. 3, in which response curves are shown for three different coating thicknesses (0.25 mil, 0.5 mil, and 1 mil), using a bias current of rather large amplitude. The low-frequency response of each one of these tapes is very nearly proportional to the coating thickness, although the high-frequency response is the same for each thickness. This suggests that short-wavelength recordings are restricted to an extremely thin layer on the surface of the tape. This phenomenon is well known[2] and is probably attributable, in large part, to self-demagnetization of the deeper layers.

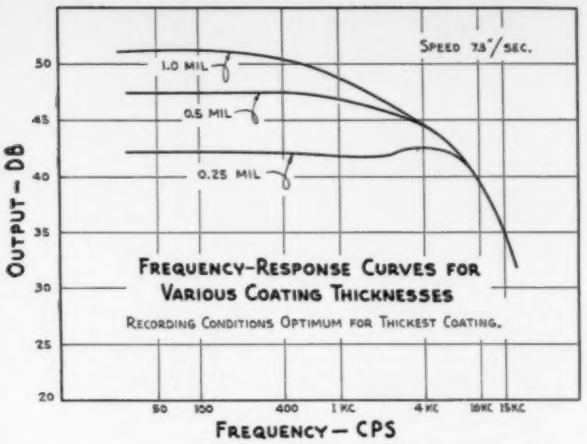

FIG. 3. Response curves for magnetic coatings of three different thicknesses (0.25 mil, 0.5 mil, and 1 mil). A bias current of rather large amplitude was used in making this series of tests. The high-frequency response is the same for each coating thickness.

When the same frequency runs were repeated, using a lower value of bias current, the curves of Fig. 4 resulted. It is apparent, that for the lower value of bias, the output does not vary appreciably at any frequency among the three tapes of different coating thickness. This is because the depth of the recording is restricted approximately to the depth represented by the thinnest coating; the additional coating material of the thicker tapes is not magnetized during recording. The fact that the unmagnetized layers of coating do not have any appreciable "shunting" effect upon the surface magnetization is probably due to the relatively low permeability of the coating at low field intensities. The high-frequency output, in the low-bias recording condition, is up appreciably (some 8 db at a wavelength of 0.5 mil) due to the improved recording definition, as previously explained.

The above series of experiments may be summarized in the following statements applicable only to similar tape constructions differing only in coating thickness.

1. The low-frequency output of a tape varies approximately as the coating thickness, provided a sufficient recording bias is used to magnetize the full depth of coating.
2. The response of a thin tape is the same as that of a thick tape, provided the latter is recorded with a value of bias current just sufficient to magnetize the thin tape.
3. The greater the recording bias (i.e., the greater the depth of recording) the lower will be the relative magnitude of the high-frequency response.

These principles suggest an interesting departure from the usual recording procedure. There may be no particular merit in increasing the recording signals well beyond the optimum conditions and suffering reduction in high-frequency response, except possibly to render the recording process more insensitive to separation of the tape from the record head. Nevertheless, operation at bias levels considerably less than "optimum" to obtain better high-frequency response may be an attractive possibility. Indeed, in systems designed for the ultimate in frequency response, the usual concepts of optimum bias, tape thickness, and equalization lose all meaning.

Returning now to a more conventional approach, we shall examine the relative response characteristics of the three tapes of different coating thickness when a recording is made on each under conditions that are optimum for each individual tape, respectively. It is apparent from Fig. 5 that the differences among the three tapes are now most pronounced. As the recording signal is increased to accommodate the thicker coatings, not only is the extra coating material brought into play to increase the low-frequency output, but the definition suffers because of the increased recording depth. The high-frequency output is reduced, as well.

INTRINSIC COATING PROPERTIES

Having described in a general way the effect of recording depth on the performance of magnetic tape, we shall now turn to the intrinsic magnetic properties of the coating itself. In connection with the theoretical explanation of the recording process, the static-induction-versus-peak-field-intensity curve (Fig. 2) was employed to predict the approximate

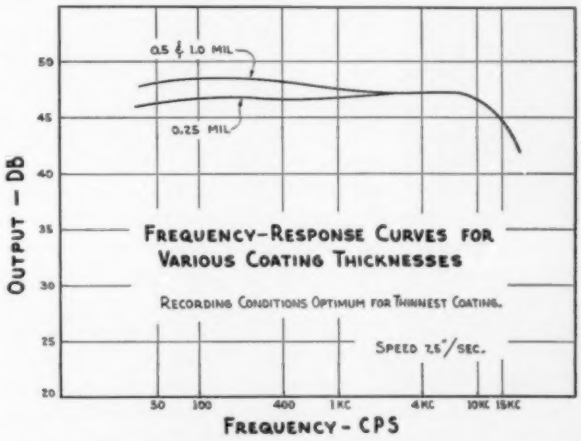

FIG. 4. The same frequency runs and the same series of coating thicknesses as in the tests of Fig. 3, *except that a much lower value of bias current was employed.* For the lower value of bias the output does not vary appreciably at any frequency among the three tapes.

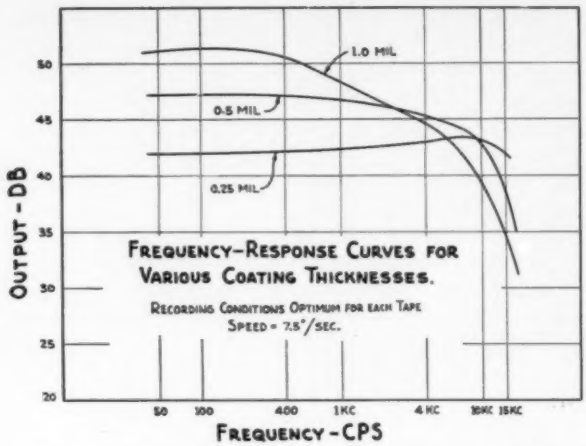

FIG. 5. Frequency-response curves of three tapes of different coating thicknesses, with the recording on each individual tape made under conditions optimal for that particular tape. The differences among the three tapes are now most pronounced.

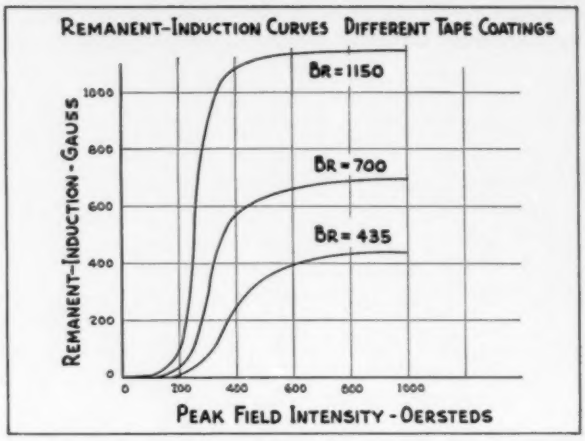

FIG. 6. The characteristics of three different tape coatings which were prepared for a series of tests designed to show the effect on performance of the total remanent induction available in each coating. The coating thickness was the same for each tape.

values of field intensities needed to magnetize the coating. Using a similar technique, a number of coating variables will be examined and the effects upon tape performance empirically determined.

It might be expected that the total remanent induction, B_r, available in the coating would have a marked effect upon tape performance. Therefore, three different tape coatings, covering a considerable range of magnetic remanence, were prepared and tested. The remanent induction curves of these materials are shown in Fig. 6. The coating thickness was the same for each tape, and—as was predicted from the B_r–versus–H_{peak} curves—the bias requirements for the tapes are almost identical. It is apparent from the response curves of Fig. 7 that the low-frequency output varies almost directly with the remanence of these tapes. However, the high-frequency response characteristics of the individual tapes tend toward a common value, showing no marked increase for the higher-remanence tapes. The tape with the lowest remanence exhibits somewhat weaker high-frequency response; a fact probably attributable to the greater curvature of the B_r–versus–H_{peak} characteristic. Thus, it would appear that only the low-frequency output is influenced by the magnetic remanence of the coating. It is significant to note that—unlike the case where thick coatings are used—the bias requirements are not necessarily increased for high-remanence materials.

ORIENTATION OF MAGNETIC PARTICLES

If the active particles of a tape coating are magnetically anisotropic (as, for instance, the acicular crystals of synthetic ferric oxide) the remanent induction of the coating can be increased appreciably by orienting the particles in the favorable direction for recording. A typical example is illustrated in the B_r–versus–H_{peak} curves of Fig. 8, showing properties of favorably and unfavorably oriented materials in comparison with those of a randomly oriented sample. The effect of orientation is to increase the remanent induction by about 10%; this is accompanied by an appreciable increase in abruptness of the B_r–versus–H_{peak} curve. This produces the rather surprising results shown in Fig. 9. Un-

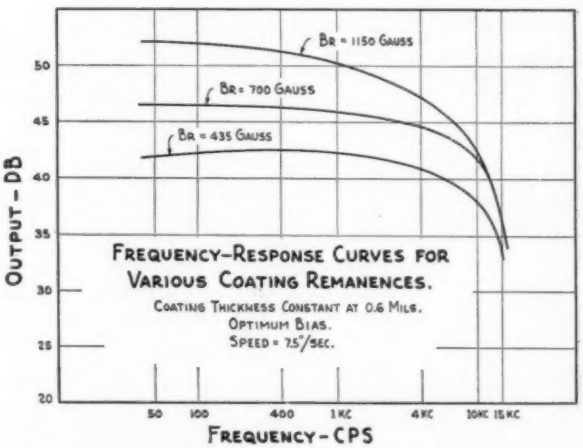

FIG. 7. Frequency-response curves for three different values of total remanent induction. (The tapes are those of Fig. 6.) The bias requirements of the tapes are almost identical. The low-frequency output varies almost directly with the remanence of the tapes. The high-frequency output values of the different tapes, on the other hand, tend toward common values.

like what happens when either remanence or coating thickness are increased, the response characteristic of properly *oriented* tape is better—at both low and high frequencies—than that of the randomly oriented sample. The improved low-frequency response is undoubtedly due to the higher remanence; the better high-frequency response is probably attributable to the abruptness of the B_r–versus–H_{peak} curve. Orientation of the particles in the magnetic coating produces another fortuitous benefit in lowering the noise level of the tape by 6 or 8 db. Thus, it is possible to realize a substantial improvement in signal-to-noise ratio from oriented coatings.

Cautions with Respect to Orientation

The response curve for unfavorably oriented tape (i.e., where the recording is made at 90° to the direction of orientation) is included to illustrate the problems which might arise if oriented material is used without due regard for recording *direction*. Particle orientation is obviously unsuitable for magnetic discs. Even when sheet records are cut from oriented magnetic stock, it is important to know the recording direction in advance.

Cases Where the Orientation Vector is Tilted

An interesting phenomenon has been observed in connection with imperfectly oriented coatings where the orientation vector is tilted with respect to the tape surface. Under these conditions, the tape sensitivity may be different for different directions of tape travel during recording. The sensitivity change is particularly great for short wavelengths and for high values of bias current. This sensitivity change may reach a total of 6 db.

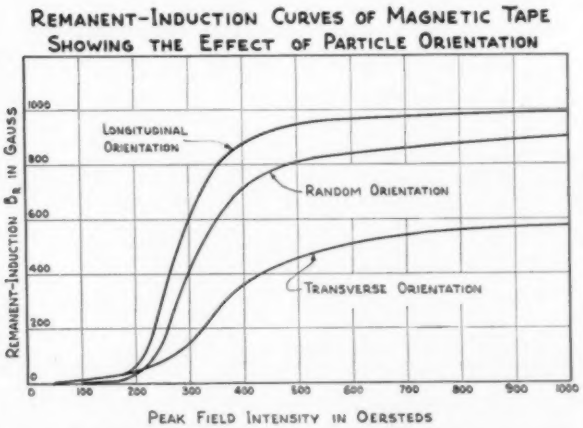

FIG. 8. Where the active particles of a tape coating are magnetically anisotropic, the remanent induction can be increased appreciably by proper orientation. Here, the magnetic properties of favorably and unfavorably oriented materials are compared with the properties of a randomly oriented sample.

For an explanation of this effect, we must refer again to Fig. 2, from which it is apparent that fields in the recording zone II may have an appreciable vertical component. Therefore, the sense of the orientation tilt may be either the same or opposite to that of the recording fields, depending upon the direction of tape travel. This observed phenomenon further corroborates the recording model in which vertical field components play an important part in the recording process. In properly oriented tapes, the aforementioned sensitivity change may be held to an insignificant fraction of a decibel.

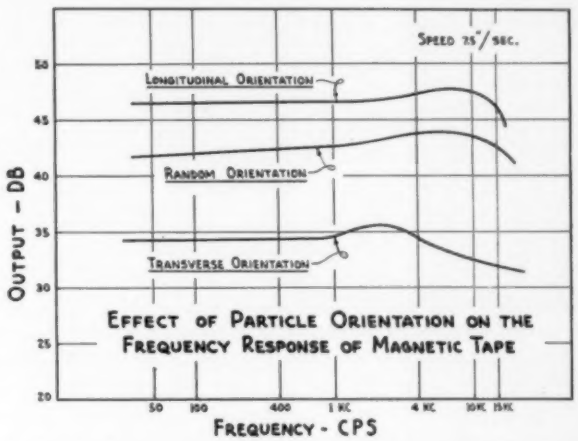

FIG. 9. Comparison of the frequency-response curves for tape coatings with three conditions of magnetic-particle orientation, respectively: *a*. With the particles *favorably* oriented with respect to the recording direction. *b*. With the particles *randomly* oriented. *c*. With the particles oriented at 90° to the direction of recording.

PRINT-THROUGH

While the layer-to-layer print effect depends upon the basic properties of magnetic materials and upon recording and storage conditions, it is also influenced to a certain extent by tape design considerations. The effect of the wavelength of the recorded signal and of the separation of the tape layers upon print sensitivity has been well explored.[2] It suffices to note that print sensitivity decreases at long wavelengths because of the decreasing recorded pole density; print sensitivity also decreases at short wavelengths because of "merging" of the fields which surround successive recorded poles on the tape. This produces a sensitivity characteristic with a maximum in the mid-audio-frequency range. As shown in Fig. 10, if the thickness of the tape base is increased, both the amplitude and frequency of this maximum are lowered.

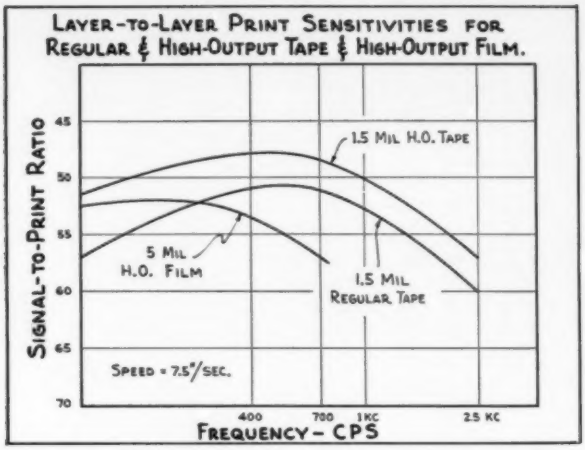

FIG. 10. Signal-to-print ratio versus frequency for three different magnetically coated materials. The samples were stored for 4 hours at 150°F. immediately after recording and prior to the making of the measurements.

The magnitude of the print (i.e. the signal-to-print ratio) depends not only upon the above-mentioned factors, but upon the total induction capabilities of the coating. This is illustrated by a comparison of the signal-to-print curves of regular and high-output tape in Fig. 10. Since print increases with time and temperature, the samples represented by the curves of Fig. 10, were stored for 4 hours at 150°F. immediately after recording and before measuring the print. Similar experiments have shown that the print signal increases for tapes having thick coatings, as well as for high-remanence materials.

PRACTICAL TAPE DESIGN PROBLEM

The design considerations discussed thus far by no means completely determine the performance of a magnetic tape. Such factors as coating uniformity and surface smoothness may also play an important part. These, however, fall properly within the province of manufacturing skill and are not usually under the control of the design engineer, even if he wished to alter them. It remains, then, to examine the various design factors as they relate to practical tape constructions. Magnetic film for motion-picture sound use and tape for high-frequency recording are used as examples.

Design of a Magnetic Film for Motion-Picture Sound

In the case of magnetic film for motion-picture sound, certain fixed conditions are established by current practice: The base material must be 5-mil film to withstand the stresses of the sprocket drive and to provide mechanical characteristics comparable to those of standard photographic film. The film speed—90 feet per minute, which is standard in 35-mm theatrical practice—and the 7500- or 8000-cps audio bandwidth which is customary in good release prints, both point to a minimum wavelength of slightly over 2 mils as the high-frequency resolution requirement. This requirement can easily be met. Furthermore, some advantage may be taken of the inherently low print properties contributed by the 5-mil thickness of the film support. These conditions suggest the use of a high-remanence coating, such as that represented by the top curve of Fig. 7, in order to afford a substantial advantage in signal-to-noise ratio. If a standard coating thickness (i.e., about 0.7 mil) is chosen, the bias requirements will be the same as that of standard magnetic films, thus providing an additional measure of interchangeability. We feel that in magnetic film, the fall-off in high-frequency response attributable to the high-density coating is scarcely noticeable over the relatively limited frequency range currently utilized in motion-picture sound recording; also, we find that the signal-to-print ratio is more than adequate. (See Fig. 10.) Since motion-picture film will always be recorded in the lengthwise direction, full advantage may be taken of magnetic orientation. Our final design of a high-output type of coating[5] on 5-mil base (Scotch brand no. 125 film) seems to be meeting with increasing acceptance in the field of motion-picture sound.

Design of a Tape for Recording High Frequencies

In the design of a tape for recording high frequencies, the objectives are somewhat different. If the speed of the tape is to be held to a reasonably low figure, the minimum recorded wavelength must be as small as possible. From our studies of recording depth and definition, we find it is necessary to reduce the recording signals (i.e., the bias and audio) in order to obtain a shallow recording. Therefore, the coating need not be very thick—a factor which reduces the physical bulk of the tape and also lowers the print-through. Indeed, the tape bulk factor may be important enough in many high-frequency recording applications to warrant reduction of the backing thickness; this may now be accomplished without serious impairment of the signal-to-print ratio.

Thus far, we have succeeded in maximizing the short-wavelength response, but at the expense of low-frequency output, due to the restricted depth of recording. By the use of a high-density coating, it is possible to restore the low-frequency output to a large extent, without impairing the high-frequency output. (See Fig. 7.) The resulting tape construction, employing a thin coating of high-density magnetic material on a thin backing film (e.g., Scotch brand no. 190 tape) exhibits superior high-frequency performance.

[5] L. B. Lueck and W. W. Wetzel, "Performance of High-Output Magnetic Tape," *Electronics*, **26**, 131–133 (March (1953).

Seventh Annual Convention of the AES—Preliminary Report

Highlights. Forty-seven technical papers were presented. The Audio Fair (Audiorama) featured 139 exhibitors, including manufacturers, distributors, and publishers.

At the Banquet—over which R. H. Ranger presided as toastmaster—A. A. Pulley, completing his year at the helm, delivered the President's Report.

The newly elected officers and Governors were then introduced. They are: R. H. Ranger, President; Walter O. Stanton, Executive Vice-President; Ewing D. Nunn, Central Vice-President; Roy A. Long, Western Vice-President; Ralph A. Schlegel, Treasurer; C. J. LeBel, Secretary; Victor Brociner, Governor; C. Robert Fine, Governor; Donald J. Plunkett, Governor. Les Paul was guest speaker of the evening. He presented a motion picture showing how the Les Paul-Mary Ford multiple recordings are made and entertained the audience with a discourse on his "life and hard times" in recording.

Mr. Fairchild, as Chairman of the Awards Committee (Benjamin B. Bauer, Harry L. Bryant, John D. Colvin, F. Sumner Hall, Chester A. Rackey, Carleton R. Sawyer, and himself) presented the Annual Awards.

The John H. Potts Memorial Award was given to Lee de Forest.

The Emile Berliner Award was presented to William S. Bachmann.

The Audio Engineering Society Award went to Norman C. Pickering.

Honorary Membership in the AES was conferred on Leo L. Beranek, W. L. Everitt, and Frederick E. Terman.

The following were elected Fellows of the AES: William R. Ayres, John D. Colvin, William W. Dean, Olin L. Dupy, Julius B. Postal, Albert St. Hilaire, Arthur J. Sanial, and Lincoln Walsh.

A full report on the October 1955 Convention of the AES, accompanied by several dozen on-the-spot photos, will appear in the next issue of the JOURNAL. A detailed report on Les Paul's entertaining talk will be published.

Program of the Technical Sessions

Wednesday Morning—October 12, 1955

ANNUAL BUSINESS MEETING OF THE AES—9:00 A.M.
Installation of officers and committee reports.

AUDIO APPLICATION PROBLEMS—9:30 A.M.

Chairman: Richard H. Ranger
Rangertone, Inc., Newark, N. J.

PROBLEMS CONCERNED WITH AUDIO VISUAL EQUIPMENT EXPERIENCED BY THE MISSIONARY OVERSEAS

Harold Gallina, The Presbyterian Church U. S. A. Foreign Missions and (RAVEMCCO) — National Council of Churches of Christ, Division of Foreign Missions, New York, N. Y.

Experiences with film projection, phonograph tape recorders, slide projectors, all operated with a minimum of power facilities and very often under adverse conditions. The use of double sound tracks, one magnetic stripe and the other photographic, offers multi-lingual application so necessary in the foreign field.

A COORDINATED CHURCH AUDIO-VISUAL SYSTEM

C. R. Keith, Summit, N. J.

This paper appears in full in the present issue of the JOURNAL. *See Table of Contents.*

ALFENOL, A NEW MATERIAL FOR MAGNETIC RECORD AND REPRODUCE HEADS

Carroll W. Lufcy, Dynacor Inc., Kensington, Maryland and Wesley T. Heath, Jr., Heath Electronics Co., Washington, D. C.

Experimental magnetic record and reproduce heads fabricated from 16-Alfenol, a recent development of the Naval Ordnance Laboratory, White Oak, Maryland, were tested and compared with units made from molybdenum Permalloy. Results show that the record and reproduce heads using this newly developed material have the advantages of increased wear resistance and resolution and decreased core losses. This is brought about by the fact that Alfenol, a high aluminum-content aluminum-iron alloy, possesses good, soft magnetic properties, yet is physically hard. Applications in instrumentation, audio and theatre equipment are cited where these factors are shown to be advantageous.

THE COMPROMISE BETWEEN NOISE AND DISTORTION IN AMPLIFIER DESIGN

Rein Narma, Gotham Audio Development Corp., New York, N. Y.

Choice of circuits and electron tube operating characteristics influencing noise in low-level amplifier stages and systems.

BASIC PROPERTIES OF MULTIPLE-LOOP FEEDBACK AMPLIFIERS

Bernard Cooperman, Sonotone Corp., Elmsford, N. Y. and Robert M. Mitchell, Commercial Radio Sound Corp., New York, N. Y.

The properties of multiple-loop feedback amplifiers are discussed in so far as they differ from those of single loop feedback amplifiers. It is shown that a multiple-loop feedback amplifier can behave quite differently than a single loop amplifier with the same amount of feedback. These differences are illustrated in terms of the basic properties of amplifiers such as gain, frequency response, distortion, etc. Various schemes for arrangement of the loops are given, together with recommendations for specific applications.

ON ELECTRICAL LOADING OF MICROPHONES

R. E. Werner, Engineering Products Division, Radio Corporation of America, Camden, N. J.

This paper appears in full in the present issue of the JOURNAL. *See Table of Contents.*

Wednesday Afternoon—October 12, 1955

SOUND CREATION—2:00 P.M.

Chairman: Frank Cooper

Haskins Laboratories, Inc., New York, N. Y.

FUNDAMENTALS OF SPEECH SYNTHESIS

Homer Dudley, Bell Telephone Laboratories, Inc., Murray Hill, N. J.

This paper appears in full in the present issue of the JOURNAL. *See Table of Contents.*

USE OF SPECTROGRAMS FOR SPEECH ANALYSIS AND SYNTHESIS

John M. Borst, Haskins Laboratories, Inc., New York, N. Y.

The transformation of speech from sound to spectrogram and back to sound again is a convenient method of research. Modifications of the spectrogram, or even hand-drawn patterns, can then be used to isolate the acoustic cues by which the synthetic words are recognized. This method has yielded new information, some of which should be useful to the audio engineer. Methods of synthesis and recordings of synthesized speech are presented.

SYNTHESIS OF SPEECH BY ELECTRICAL ANALOG DEVICES

Kenneth N. Stevens, Acoustics Laboratory,
Massachusetts Institute of Technology, Cambridge, Mass.

Two electrical devices for simulating the operation of the speech mechanism are described and demonstrated by tape recordings. One synthesizer incorporates variable simple tuned circuits to represent vocal tract resonances, and can be made to generate simple sentences under the control of a teletype tape and relays, or an analyzer that extracts appropriate control signals from human speech. The other synthesizer is a variable transmission-line analog of the vocal tract.

ELECTRONIC ORGAN CONSTRUCTION

Richard H. Dorf, The Schober Organ Corp., New Hyde Park, N. Y.

Concerning an electronic organ designed for home construction, the two important design aspects are musical values — authentic pipe sounds in large variety — and physical construction methods and approaches which make assembly simple and straightforward while simultaneously yielding high long-period reliability in both function and mechanical stability. The formant type of tone coloring is discussed as an electrical analog of acoustic tone coloring in conventional instruments and as a very satisfactory basic method of musical tone synthesis in conjunction with primary wave generators of suitable type.

ELECTRONIC MUSIC SYNTHESIZER

Harry F. Olson, and Herbert Belar, RCA Laboratories, Inc.
Princeton, N. J.

The electronic music synthesizer is a machine that produces music from a coded record. The coded record is produced by a musician, musical engineer, or composer with a fundamental understanding of the composition of sound. The electronic music synthesizer provides means for the production of a tone with any frequency, intensity, growth, duration, decay, portamento, timbre, vibrato, and variation. If these properties of a tone are specified, the tone can be completely described. The advantage of the electronic music synthesizer is that it can produce new and radical tone complexes for musical satisfaction and gratification. The new system does not displace the artist and musician of today. It does not take the place of talent combined with work. The electronic music synthesizer provides the musician, musical engineer, and composer with a new musical tool with no inherent physical limitations.

Wednesday Evening—October 12, 1955

SEVENTH ANNUAL BANQUET—7:00 P. M.

Presentation of the Society's Annual Award, John H. Potts Memorial Award, Emile Berliner Award, Honorary Memberships, and Society Fellowships. ENTERTAINMENT BY LES PAUL.

Thursday Morning—October 13, 1955

MAGNETIC TAPE—9:30 A.M.

Chairman: Robert H. Carson

Naval Research Laboratory, Washington, D. C.

MAGNETIC PROPERTIES OF RECORDING TAPE PIGMENT

J. Gittleman, Franklin Institute Laboratory for Research and Development, Philadelphia, Pa.

This paper appears in full in the present issue of the JOURNAL. *See Table of Contents.*

THE INFLUENCE OF MAGNETIC PIGMENT PROPERTIES ON COATED RECORDING MEDIA

Ernest W. Franck and Edward Schmidt, Reeves Soundcraft Corp., Springdale, Conn.

The use and characteristics of a new type of synthetic iron oxide magnetic pigment are discussed in its application in the standard sound recording tape, motion picture magnetic film and instrumentation tape fields. Factors other than magnetic properties of the pigment which affect tape performance are discussed.

BIAS CHARACTERISTICS OF TAPE RECORDERS

Frank Radocy and Andreas Kramer, Audio Devices, Incorporated, New York, N. Y.

A survey of bias characteristics on 57 tape recorders, ranging in price from $140 to $2,000, revealed a wide variation in effective bias among recorders of different make. The increasing popularity of "long recording" type tapes, which possess sharper bias-output characteristics, magnifies the problem of setting operating bias current so that the ultimate in performance can be obtained from the tape.

A DIRECT-READING B-H METER

Andreas Kramer, Audio Devices, Incorporated, New York, N. Y.

In the manufacture of magnetic iron oxide for recording tape, frequent tests must be made in order to maintain uniformity of the product. The simplest and quickest method has been a B-H loop tracer, where the hysteresis loop is traced on the screen of a cathode-ray tube. This involves centering the pattern and reading the results on a previously calibrated screen and requires time and experience. This paper describes a method of testing magnetic materials, particularly magnetic iron oxide, in which the most important properties, i.e., B_m, B_r, H_m and H_c, are indicated directly on a meter with a calibrated scale.

A NEW CONCEPT OF MAGNETIC RECORDING MEDIA

J. Herbert Orr, Orradio Industries, Inc. Opelika, Ala.

Evils of fast-working solvents in conventional magnetic coating. Microscopic craters — causes and effects. Casting of homogeneous magnetic film for hot-melt lamination. Non-clustering lattice pigment Qualitative separation of magnetic particles through air glass conversion. Application of this to magnetic recording media.

SOME DESIGN CRITERIA FOR MAGNETIC TAPE

R. A. von Behren, Minnesota Mining & Manufacturing Co., St. Paul, Minn.

This paper appears in full in the present issue of the JOURNAL. *See Table of Contents.*

Thursday Afternoon—October 13, 1955

TRANSISTOR APPLICATION PROBLEMS—1:30 P.M.

Chairman: Harry L. Owens*

Signal Corps Engineering Laboratories, Fort Monmouth, N. J.

PRACTICAL APPLICATIONS OF JUNCTION TRANSISTORS TO AUDIO EQUIPMENT

William D. Bevitt, CBS-Hytron, Inc., Danvers, Mass.

The audio engineer may apply transistors advantageously to portable battery-operated equipment. A transistorized microphone preamplifier can be housed inside the microphone case to preserve high-frequency response. Transistors permit the construction of a compact, remote broadcast amplifier. We can build a lightweight, self-contained electronic megaphone with transistors. The reluctance phonograph pickup can achieve full fidelity with a closely mounted transistor preamplifier. A high-fidelity power amplifier will operate, with power transistors, from a 12-volt storage battery with relatively low current drain. Each of the above devices is demonstrated.

HIGH QUALITY AUDIO AMPLIFIERS USING TRANSISTORS

H. W. Abbott, General Electric Company, Electronic Laboratory, Syracuse, N. Y.

Use of transistors in high-quality audio amplifiers offers advantages, particularly in the field of low-level audio preamplifiers such as those used in broadcast stations. Some of the advantages are reduced power dissipation, lower dc operation levels, hum reduction and the possibility of matching the amplifier to low impedance inputs and outputs without the use of transformers. This paper discusses the design, performance and limitation of high quality audio amplifiers. As an example, a high-fidelity preamplifier having a power output of 18 dbm, a gain of 40 db, response within 1 db from 50 cps to 15 kcs and distortion less than 0.5% over this frequency range is described.

TRANSISTOR AUDIO POWER OUTPUT STAGES

James F. Marshall and Donald Mogen, Minneapolis-Honeywell Regulator Company, Minneapolis, Minn.

The characteristics of the common-base, common-emitter and common-collector circuits are analyzed for their advantages and disadvantages for audio work. Bias stabilization, crossover distortion, and harmonic distortion are discussed for several circuits, and the basic design procedures are outlined. Transistors approach a theoretical amplifier much more closely than do vacuum tubes, so that it is reasonable to expect that circuit development will enable the transistor to approach and ultimately surpass the performance of vacuum tubes with a power-supply efficiency unattainable with tubes.

SOME PRACTICAL CONSIDERATIONS CONCERNING THE LIMITING OPERATING VOLTAGES OF JUNCTION TRANSISTORS

W. E. Sheehan, Raytheon Manufacturing Company, Newton, Mass.

Limitations discussed are voltage, avalanche and push-through breakdowns; the alpha multiplication effect; breakdown with the base shorted to the emitter; and voltage breakdown. These are studied for low-power audio transistors, rf units and medium- and high-power transistors.

AN AUDIO FREQUENCY TRANSISTOR AMPLIFIER WITH 40 DB OF NEGATIVE FEEDBACK

R. J. Kircher, Bell Telephone Laboratories, Inc., Murray Hill, N. J.

This paper discusses design principles in the application of negative feedback to transistor amplifiers. A specific audio-frequency amplifier design will be used to illustrate the application of these ideas in order to realize 40 db or more of negative feedback across the band with satisfactory gain and phase margins for stability.

Three direct-coupled, cascaded, common-emitter stages using alternating conductivity-type junction transistors are used with suitable transmission-shaping circuits, and an overall shunt feedback connection. Power is supplied by a single 48-volt dc supply.

Design considerations include setting of dc operating points for the stages; transmission shaping methods, i.e., use of local negative feedback, interstage shaping networks; overall amplitude and phase relationships.

SOME PRACTICAL ASPECTS OF TRANSISTOR AUDIO CIRCUIT DESIGN

S. Sem-Sandberg, Hughes Aircraft Company, Culver City, Calif.

The purpose of this paper is to make an attempt to bridge some of the gaps between the existing theory of junction transistors, and the practical design of transistorized audio circuits. Through an example, a 10-watt high-fidelity amplifier, a method of approach to the practical design is shown, illustrating high, medium and low power stages with various bias arrangements. Emphasis is placed on a design for large-scale production, and on how to choose transistors and transistor complements in view of finished-product specifications and good economy.

Friday Morning—October 14, 1955

STANDARDS AND MEASUREMENTS—9:30 A.M.

Chairman: Sherman Fairchild

Fairchild Recording Equipment Co., Whitestone, L. I., N. Y.

FREE-FIELD TECHNIQUES FOR SECONDARY STANDARD CALIBRATION OF MICROPHONES

Arnold Seligson, Material Laboratory, New York Naval Shipyard, Brooklyn, N. Y.

The acoustic environment required for the performance of free-field secondary standard calibration of microphones is examined. Automatic sound-pressure level control of the sound source is utilized, requiring that measuring and test microphones be carefully placed in the sound field. Results obtained from various microphone orientations are presented with a view towards minimizing errors derived from non-uniformity in the sound field.

LOCKED CONCENTRIC GROOVED DISC FOR USE IN MEASUREMENTS OF DISC REPRODUCER PERFORMANCE

Jack Feinstein, Material Laboratory, New York Naval Shipyard, Brooklyn, N. Y.

When using spiral-groove frequency test records as the signal source for the determination of disc-reproducer performance, it is recognized that a gradual decrease in reproduced level occurs from the outside to the inside of the disc. Along with this, there occur instantaneous variations which tend to reduce the accuracy of measurements. It was felt that these difficulties could be minimized by the use of locked concentric grooves. The relative merits of both types of grooves are discussed, and experimental data presented.

* C. R. Sawyer, Bell Telephone Laboratories, Inc., Whippany, N. J. substituted in Mr. Owens' absence.

Tone-Burst Testing

C. J. LeBel, Audio Instrument Company, Inc., New York, N. Y.

It has been shown by Olson that tone-burst transient effects may be more important than frequency response and distortion data, in defining audio performance. A simple method for transient testing, by the tone-burst method, is described; it includes means for generating a repetitive tone burst, as well as a logarithmic system for analyzing the result. It is pointed out that a tone-burst test will measure relaxation transients, which a square-wave test ordinarily will not. In some amplifiers such transients occur at so low a frequency that the loudspeaker cone is driven in an unloaded condition, producing serious intermodulation within the loudspeaker. This effect has hitherto been neglected.

Some Experiences with Mass Production Tape Duplication

Cecil S. Bidlack, National Association of Educational Broadcasters, Urbana, Ill.

The NAEB radio network is a cooperative organization operated by the National Association of Educational Broadcasters for its member stations who are owned by educational institutions, municipalities and other public-service agencies. Since its beginning in 1950, it has grown to the point where it is now serving nearly 100 member stations. It provides a program service of up to 9 hours per week distributed on magnetic tape. By the use of 2 mass duplicators, each of which will produce 11 simultaneous copies of a master tape, the network turns out upwards of 1200 tapes per week for shipment to its members.

Aspects of Distortion Measurement in Sound Systems

Mitchell A. Cotter, Consumers Union of the U. S., Inc., Mt. Vernon, N. Y.

After a brief resume of distortion-measurement techniques in sound systems, the concept of the system transfer function is developed. Existing standard techniques of distortion measurement reveal many shortcomings when examined through this formulation. Consideration of many system characteristics suggest some new approaches which would more effectively define the system transfer function (test device). Several of these new techniques are discussed. Some methods employing a modified noise source are illustrated and test examples given.

Friday Afternoon—October 14, 1955

DISC RECORDING—1:30 P.M.

Chairman: E. V. B. Kettleman
RCA Victor Recording Division, Radio Corporation of America, New York, N. Y.

Audio Console Design Notes

Philip C. Erhorn, Audiofax Associates, Incorporated, New York, N. Y.

This is a discussion of functional, modern control-console design, primarily applied to recording-studio needs. There will be included several microphone mixing consoles and also an editing console for tape work. Use of push buttons for echo selection and for selecting multiple inputs through one or two high-level positions is demonstrated. Dual-channel design, affording either sub-mixing or stereo operation in one console, is included. Self-contained amplifying equipment is featured. Individual-channel equalizers for correction of room acoustics are discussed.

Console for the Selection and Transmission of Delayed Broadcast Progams

Ralph A. Schlegel, WOR Division of General Teleradio, Inc. New York, N. Y.

This paper is a discussion of an audio console capable of simultaneously recording from any one or all of six program sources while transmitting (via tape, disc or live material) to any one or all of six outgoing program lines. The console is primarily for delay broadcasting during daylight-saving-time periods.

A Complete Disc-Recording Channel

Stephen F. Temmer, Rein Narma, John G. McKnight, Gotham Audio Development Corporation, New York, N. Y.

Some details of the design and construction of a lateral-feedback disc-recording system are described, showing the interrelationship between the cutterhead and amplifier with respect to the equalization, power requirements and distortion; simplicity and reliability are emphasized. A new balanced FM modulator-discriminator used for measuring the overall response is also described.

The Half-Mil Diamond for Microgroove Records

Emory Cook, Cook Laboratories, Inc., Stamford, Conn.

Preliminary information on the use of ½-mil radius diamond playback points on typical commercial pressings and on V-groove pressings. Effects on frequency and transient response, wear, wave form distortion, effective tracing pressures, noise, etc.

Quality Control in Recording Studio Operations

Donald J. Plunkett, Capitol Records, Inc., New York, N. Y.

The paper is a description of the various means of information and program storage and the methods of quality control of these media as practiced in modern recording-studio operation. A brief history of the recording art from acoustic recording to tape and fine-groove recording should highlight the strides made in recording-studio quality control.

Recent Developments in Precision Master Recording Lathes

Jerry B. Minter, Components Corporation, Denville, N. J.

Work on the Hydrofeed master recording lathe actually began almost 20 years ago. The increased standards of performance required to produce the micro-groove LP record are easily met by this new development. Basically this lathe differs from previous ones in the use of a hydraulic feed system, for the transverse feed, rather than a lead screw. Many other novel improvements are described in the paper, such as: automatic pitch control, reduction of wow, flutter, and rumble to very small levels, and automatic operation throughout the operation cycle.

The Recording of Acetate Masters for the Commercial Record Manufacturer

Allen Weintraub, Bell Sound Studios, Inc., New York, N. Y.

A discussion of some of the limitations imposed on the recording studio by the record manufacturers, and techniques used to accommodate these limitations. Some of the items covered will be variable pitch cutting of long playing records, the problem of groove echo in disc recording, etc.

A Servomechanism for Automatic Disc Feed Control

W. Robert Dresser, Graphic Recorders, Inc., Bridgeport, Conn.

The use of servomechanisms for the continuous controlling of the feed-screw ratio of disc-recording lathes was first introduced at the

Audio Fair in 1950. This paper describes one of the more recent adaptations of feed-control servomechanisms, which provides automatic anticipation of record-groove requirements by means of an advance head for tape rerecordings, to provide the variable groove pitch of the extended play records.

Saturday Morning—October 15, 1955

HIGH FIDELITY, GOOD OR BAD?—9:30 A.M.

Chairman: S. J. Begun
Clevite-Brush Development Co., Cleveland, Ohio

Tonal Balance in Conventional Music

Norman C. Pickering, Pickering & Company, Inc., Oceanside, N. Y.
In the earlier days of electrical sound recording, considerable work was done at the Bell Telephone Laboratories on the power and frequency ranges of musical instruments and groups of instruments. Recent work on the frequency spectrum of music, sometimes called tonal balance, has confirmed the published work of Sivian, Dunn and White and has led to a theory of record compensation based on the results. An automatic device for setting equalizer curves is described.

Barriers to Good Record Reproduction

Mitchell A. Cotter, Consumers Union of the U. S., Inc., Mt. Vernon, N. Y.
This paper begins with a brief discussion of the general system parameters in a record playback device. Several new factors are introduced. Recording and record-material factors are shown to contribute significantly to many of the present-day problems. Limitations which result in greatly superior performance and design demands are proposed. Numerical examples of an analysis of typical equipment are given. A bibliography of many important papers on the subject is included, along with several design tables and charts.

The Consumer's Viewpoint on High Fidelity

Donald M. Berk, Consumers' Research, Inc., Washington, N. J.
The various attitudes of the manufacturers, which are exemplified in their advertising and in their relationships with customers, are in need of some change and clarification. This is indicated by certain unsatisfactory customer-manufacturer relationships, which affect many people who would like to buy high-fidelity equipment, but are discouraged in their efforts to do so. Based upon CR's experience and wide correspondence in the field of high fidelity, it is felt that certain changes in design details and trade practices will help bring the manufacturer, distributor, and consumer to a better mutual understanding. There will be a critical discussion of a few typical products and trade practices. Suggestions will be presented which should be regarded as generally helpful to the industry in its relationships with ultimate consumers.

Evaluating "Hi-Fi" Components for the Consumer

Julian D. Hirsch and Milton Weiss, The Audio League.
Pleasantville, N. Y.
The multiplicity of types and makes of "hi-fi" equipment on the market makes it difficult for the prospective purchaser to make an intelligent choice. A set of reasonable standards is needed by which the consumer can judge the importance of various equipment features. A consumer "hi-fi" evaluation service must use, as its major criterion, the final reproduced sound. Sufficient technical data must be included so that the technical audiophile may independently reach intelligent decisions without further testing—except listening tests. The purchaser must be guided among the conflicting claims of manufacturers. These claims are often based on different standards and terms. The various sides of different philosophies should be clearly presented to the consumer so that he may select the course most appropriate for his personal needs.

Saturday Afternoon—October 15, 1955

AUDIO EQUIPMENT—1:30 P.M.

Chairman: F. V. Hunt
Cruft Laboratory, Harvard University, Cambridge, Mass.

Mechanical Crossover Characteristics in Dual-Diaphragm Loudspeakers

Abraham B. Cohen, University Loudspeakers, Inc., White Plains, N. Y.
It is possible to obtain mechanical separation of low- and high-frequency energy from a single voice-coil moving system by the application of auxiliary apex-mounted diffuser-type radiating elements. The dual response characteristic of this structure is a function of the size and weight of the auxiliary diaphragm and the manner in which it is uncoupled from the low frequency cone. A laboratory demonstration is made of the construction of such a dual-diaphragm loudspeaker. Curves are run before and after application of the high-frequency element.

Tweeter Design Considerations

George W. Sioles, University Loudspeakers, Inc., White Plains, N. Y.
This paper covers the general constructional and design characteristics of various types of tweeters, and elaborates on the fundamental design problems of the moving-coil, horn-loaded tweeter. The paper covers air-chamber requirements, magnet and gap design, horn characteristics, etc. Performance, reliability, and cost considerations are discussed for the various types.

Conversion Efficiency in "Hi-Fi" Loudspeakers

Saul J. White, Racon Electric Co., New York, N. Y.
This paper discusses the pros and cons of high absolute conversion efficiency in "hi-fi" loudspeakers. Because most amplifiers in home reproducing systems have ample reserve power, there is a trend to deprecate the importance of high speaker efficiency. This paper outlines the areas where definite improvement in performance is realizable through high conversion efficiency, and also indicates performance factors where efficiency is of secondary value. The effect of speaker efficiency upon response linearity, transients, Q, and amplifier damping control is discussed. In view of these efficiency factors, the insertion of an attenuator during A-B demonstration tests tends to lower the performance of the higher efficiency speaker.

Measurement and Rating of Loudspeaker Characteristics

Peter D. Collings-Wells, Goodmans Industries, Ltd.,
Wembly, Middlesex, England
This paper appears in full in the present issue of the Journal. *See Table of Contents.*

Magnetic Pickups and Proper Playback Equalization

Walter O. Stanton, Pickering & Company, Inc., Oceanside, N. Y.
This paper appears in full in the present issue of the Journal. *See Table of Contents.*

A D'Arsonval Movement Electrodynamic Phonograph Cartridge

J. H. McConnell, Electro-Sonic Laboratories, Long Island City, N. Y.
This paper describes three types of moving-coil phonograph cartridges,

built precisely like a miniature D'Arsonval meter movement. Advantages of this design are linear operation over a very wide frequency range, very small dynamic mass, relatively great lateral compliance, constant very low impedance over the entire audio spectrum, relatively great power output, and almost absolute insensitivity to vertical motion of the stylus.

The dynamic mass of two of these cartridges is 1 milligram or less. The lateral compliance approaches 7 x 10^{-6} cm/dyne. Since these characteristics raise the plastic resonance peak encountered with modern microgroove recordings, manufactured of yielding material, to over 20 kcs, very smooth and clean performance results.

THE RADIAL TONE ARM — A NEW PHONOGRAPHIC PICKUP SUSPENSION
H. E. Roys, Radio Corporation of America, Camden, N. J. and E. E. Masterson, Eckert-Mauchly Division, Remington Rand, Inc., Philadelphia, Pa.

A new method of supporting a pickup while reproducing a phonograph record is described. The arrangement permits the pickup to follow along a radial line, thus eliminating tracking error. Static friction is greatly reduced so that the force required to pull the pickup across the record is small. In addition, the arrangement provides mechanical resistance that is effective in a lateral direction and hence effective in damping tone-arm resonance. The damping is ineffective in a vertical direction, however, so that the pickup readily follows warped records.

Exhibitors at Audiorama 1955, New York

Following are the companies which participated in Audiorama 1955. Their products are included in the listing.

Acoustic Research, Inc.
23 Mt. Auburn St., Cambridge 38, Mass.
Loudspeaker systems.

Aero Products Co.
369 Shurs Lane, Philadelphia 28, Pa.
Transformers.

All-State Distributors, Inc.
457 Chancellor Ave., Newark, N. J.
Distributors: Tape recorders; phonographs; record changers.

Altec Lansing Corp.
161 Sixth Ave., New York 13, N. Y.
Loudspeakers; condenser microphones; loudspeaker enclosures; accessories; semi-assembled systems for hi-fi novices.

American Elite, Inc.
7 Park Ave., New York 16, N. Y.
Microphones; radios; tape recorders; record players; vacuum tubes; audio components.

AMI Incorporated
1500 Union Ave., S. E., Grand Rapids 2, Mich.
Juke boxes; extension speakers; background music systems.

Ampex Corporation
934 Charter St., Redwood City, Calif.
Magnetic tape recorders; speaker-amplifier combinations.

Ampro Corporation
2835 N. Western Ave., Chicago 18, Ill.
Tape recorders.

Audak Company
500 Fifth Ave., New York 36, N. Y.
Audio equipment; pickups.

Audio Artisans, Inc.
396 Saw Mill River Rd., Hawthorne, N. Y.
Miniature preamplifiers.

Audio Devices, Inc.
444 Madison Ave., New York 22, N. Y.
Tape in color, on colored reels. Tape on standard base and on Mylar polyester base for instrumentation purposes; magnetic film for motion-picture applications; recording discs; phonograph needles and styli.

The Audio Exchange, Inc.
159-19 Hillside Ave., Jamaica 32, N. Y.
Distributors for many manufacturers; this firm buys, sells, and trades new and used components; manufactures foam-rubber turntable discs.

The Audio Fair
67 W. 44th St., New York 36, N. Y.
Business management of the Audio Fair.

Audio Fair Publishers
67 W. 44th St., New York 36, N. Y.
Publisher: *Audio Fair,* buyer's guide and directory.

Audiogersh Corp.
254 Grand Ave., New Haven 13, Conn.
Record changers; record players; accessories.

A-V Tape Libraries, Inc.
730 Fifth Ave., New York 19, N. Y.
Recorded tapes (popular and classical music, educational, literary, and religious material recorded on magnetic tape).

Bard Record Co., Inc.
66 Mechanic St., New Rochelle, N. Y.
Tone arms.

Beam Instruments Corp.
350 Fifth Ave., New York 1, N. Y.
Loudspeakers; amplifiers; enclosures.

Bell Sound Systems, Inc.
555 Marion Rd., Columbus 7, Ohio
Tape recorders; audio components.

Berkshire Recording Corp.
150 W. 90th St., New York 24, N. Y.
Pre-recorded tapes.

Berlant-Concertone
Audio Division, American Electronics, Inc.
4917 W. Jefferson Blvd., Los Angeles 16, Calif.
Tape recorders and accessories; four-channel mixers.

David Bogen Co., Inc.
29 9th Ave., New York 14, N. Y.
Amplifiers; preamplifiers; receivers; tuners; turntables.

The R. T. Bozak Company
P.O. Box 966, Darien, Conn.
Loudspeakers.

British Industries Corp.
80 Shore Rd., Port Washington, N. Y.
Distributors: record changers; phonograph equipment; amplifiers; loudspeakers; enclosures.

British Radio Electronics, Ltd.
1833 Jefferson Pl. N. W., Washington 6, D.C.
Amplifiers; record players; loudspeaker systems; amplifier kit sets.

Brociner Electronics Corp.
344 E. 32nd St., New York 16, N. Y.
Amplifiers; preamplifier-equalizers; corner horns.

Cabinart
(G. & H. Wood Products Co., Inc.)
99 N. 11th St., Brooklyn 11, N. Y.
Loudspeaker systems; corner-horn speaker enclosures; equipment cabinets.

Capehart-Farnsworth Company
3700 E. Pontiac, Ft. Wayne, Ind.
Radio-phonograph combinations; phonographs; radios.

Chemtron Industries, Inc.
100 Fifth Ave., New York 11, N. Y.
Portable AM-FM phonograph combinations.

Columbia Records, Inc.
(Times Columbia, NYC)
799 Seventh Ave., New York 19, N. Y.
Phonograph records; phonographs; tape recorders.

Components Corporation
106 Main St., Denville, N. J.
Turntables and recording lathes.

Conrac, Inc.
19217 E. Foothill Blvd., Glendora, Calif.
Custom television chassis; remote-control units.

Cook Laboratories, Inc.
101 Second St., Stamford, Conn.
LP and two-channel records; two-channel equipment.

Custom Records, Inc. (R. I. Mendels, Inc.)
41 E. 42nd St., New York 17, N. Y.
Record pressings.

Dauntless International
750 Tenth Ave., New York 19, N. Y.
Phonograph records.

Daystrom Electric Corp.
753 Main St., Poughkeepsie, N. Y.
Magnetic tape recorders.

DeJur-Amsco Corp.
45-01 Northern Blvd., Long Island City 1, N. Y.
Tape recorders; tape recorder dictating machines.

Duotone Company, Inc.
Locust St., Keyport, N. J.
Loudspeakers; microphones; amplifiers; diamond phonograph styli.

E. I. du Pont de Nemours & Co., Inc.
(Film Department)
10th and Market Sts., Wilmington 98, Del.
Demonstrations of "Mylar" polyester film and its use as a base for magnetic recording tape.

Electro-Sonic Laboratories
35-54 36th St., Long Island City 6, N. Y.
Phonograph pickups; matching transformers; preamplifiers.

Electro-Voice, Inc.
Cecil and Carroll Sts., Buchanan, Mich.
Crystal and ceramic phonograph pickups and cartridges; microphones; loudspeakers; driver units; cellular and diffraction horns; crossover networks; speaker enclosures; FM and television boosters; preamplifiers; amplifiers; equipment consoles.

The Elektra-Stratford Record Corp.
361 Bleecker St., New York 14, N. Y.
Phonograph records; recording accessories; speaker systems; recorded tapes.

Ercona Corporation
Electronics Division
551 Fifth Ave., New York 17, N. Y.
Preamplifiers; amplifiers; record changers; record players; loudspeakers and loudspeaker enclosures.

Fairchild Recording Equipment Co.
Whitestone 57, N. Y.
Moving-coil cartridges and accessories; transcription arms; preamplifier-equalizers; turntables.

Federal Manufacturing & Engineering Corp.
1055 Stewart Ave., Garden City, N. Y.
Tape recorders.

Federated Electronics Sales
1021 U. S. Route 22, Mountainside, N. J.
Distributors: audio equipment.

Fenton Company
15 Moore St., New York 4, N. Y.
Tape recorders; record changers.

Ferranti Electric, Inc.
30 Rockefeller Plaza, New York 20, N. Y.
Phonograph pickups.

Fisher Radio Corp.
21-21 44th Drive, Long Island City 1, N. Y.
Amplifiers; audio-control units; filters; horns; phonograph cartridges; preamplifiers; preamplifier-equalizers; AM-FM tuners.

General Electric Company
Electronics Park, Syracuse, N. Y.
Variable-reluctance pickups; preamplifier-equalizers; audio equipment.

Gray Research & Development Co., Inc.
658 Hilliard St., Manchester, Conn.
Audio equipment for home and broadcast use; transcription arms; equalizers.

Grommes
Division of Precision Electronics, Inc.
9101 King St., Franklin Park, Ill.
Amplifiers.

Harman-Kardon, Inc.
520 Main St., Westbury, L. I., N. Y.
AM-FM tuners; amplifiers; combination AM-FM tuner - amplifier - power amplifier units.

Haydn-Urania Records
40 E. 19th St., New York 3, N. Y.
Phonograph records.

Heath Company
Subsidiary of Daystrom, Inc.
305 Territorial Rd., Benton Harbor, Mich.
Kit-form electronic equipment; preamplifiers; amplifiers; tuners; loudspeaker systems; test equipment.

High Fidelity
Audiocraft
The Publishing House, Great Barrington, Mass.
Publishers of the magazines *High Fidelity* and *Audiocraft;* publishers of books on recorded music and high-fidelity sound reproduction.

Interelectronics Corp.
2432 Grand Concourse, New York 58, N. Y.
Amplifiers; "consolette" with provisions for FM pickup and audio amplifier for motion picture projector.

International Electronics Corporation
(Frazier-May)
159 Howell St., Dallas, Tex.
Loudspeakers.

International Electronics Corporation
(Mullard Products)
81 Spring St., New York 12, N. Y.
Vacuum tubes and audio equipment.

Janszen Laboratory, Inc.
69 Harvey St., Cambridge 40, Mass.
Loudspeakers and enclosures.

Jensen Manufacturing Co.
6601 S. Laramie Ave., Chicago 38, Ill.
Loudspeakers; cabinets.

Karlson Associates, Inc.
1483 Coney Island Ave., Brooklyn 30, N.Y.
Enclosures.

Kingdom Products, Ltd.
23 Park Place, New York 7, N. Y.
Vacuum tubes; playback arms; loudspeakers.

Kingsway of London, Ltd.
(Division of Applied Electronics, Inc.)
487 Park Ave., New York 22, N. Y.
Phonographs; audio components.

Klipsch & Associates
P.O. Box 64, Hope, Arkansas
Loudspeakers.

Lafayette Radio
(Radio Wire Television, Inc.)
100 Sixth Ave., New York 13, N. Y.
Tuners; amplifiers; speakers; cabinets; record changers; tape recorders.

James B. Lansing Sound, Inc.
2439 Fletcher Drive, Los Angeles 39, Calif.
Loudspeakers.

Leonard Radio, Inc.
69 Cortlandt St., New York 7, N. Y.
Distributors: sound equipment; record players; tuners; amplifiers; speakers; cabinets; tapes; records.

London Records, Inc.
539 W. 25th St., New York 1, N. Y.
Phonograph records.

Magnecord, Inc.
1101 S. Kilbourn Ave., Chicago 24, Ill.
Tape recorders.

The Maico Co., Inc.
21 N. Third St., Minneapolis 1, Minn.
Audio-frequency curve tracers; hearing aids; audiometers; psychometers; sound spectrographs; auditory training systems.

Majestic International Corp.
79 Washington St., Brooklyn 1, N. Y.
Radios and radio-phonograph combinations; tape recorders.

Marantz Company
44-15 Vernon Blvd., Long Island City 1, N. Y.
Preamplifiers and amplifiers.

Mart (including Price-Fax magazine)
480 Lexington Ave., New York 17, N. Y.
Publishers of trade and consumer material.

Matsushita Electric
(R. I. Mendels, Inc.)
41 E. 42nd St., New York 17, N. Y.
Loudspeakers and portable radios.

McIntosh Laboratory Inc.
320 Water St., Binghamton, N. Y.
Amplifiers.

Mercury Record Corp.
Suite 815, 745 Fifth Ave., New York 21, N. Y.
Phonograph records.

Microlab Devices, Ltd.
1195 Lawrence Ave. W., Toronto, Ontario, Canada
Turntables.

Miessner Inventions, Inc.
Van Buren Rd., Morristown, N. J.
Electronic pianos.

Minnesota Mining and Manufacturing Co.
900 Fauquier Ave., St. Paul 6, Minn.
Magnetic recording tapes.

Mooney-Rowan Publications
Severna Park, Maryland
Publishers: *Tape Recording Magazine; The Sound Salesman.*

Motorola, Inc.
4545 W. Augusta Blvd., Chicago 51, Ill.
Phonographs; clock, table, and portable radios.

Munston Manufacturing and Service, Inc.
Beech St., Islip, L. I., New York
Amplifiers; output transformers.

National Company, Inc.
61 Sherman St., Malden 48, Mass.
AM-FM tuners; audio amplifiers; audio components.

Newcomb Audio Products Co.
6824 Lexington Ave., Hollywood 38, Calif.
Amplifiers; AM-FM tuners; phonographs; transcription players; public address equipment.

Orradio Industries, Inc.
120 Marvyn Road, Opelika, Alabama
Standard and Mylar-base recording tape; tape recording accessories.

John Ould (U.S.A.) Ltd.
519 S. Fifth Ave., Mt. Vernon, N. Y.
Amplifiers; loudspeakers and enclosures.

The Pentron Corp.
777 S. Tripp Ave., Chicago 24, Ill.
Professional and portable tape recorders; recorded tapes.

Permoflux Corp.
Distributor Division
2835 N. Kedzie Ave., Chicago 18, Ill.
Loudspeakers; loudspeaker systems; headphones.

Phonotapes, Inc.
853 Ninth Ave., New York 19, N. Y.
Pre-recorded tapes; phonograph records; audio equipment; catalogs; books.

N. Pickens Import Co.
31 E. 14th St., New York 3, N. Y.
Radio-phonographs.

Pickering and Company, Inc.
309 Woods Ave., Oceanside, N. Y.
Magnetic cartridges; pickup arms; equalizers; preamplifiers.

Pilot Radio Corp.
37-06 36th St., Long Island City 1, N. Y.
Amplifiers; preamplifiers; AM-FM and FM tuners; phonographs.

Presto Recording Corp.
P.O. Box 500, Paramus, N. J.
Disc and tape recording and reproducing equipment; lacquer-coated aluminum blank recording discs.

Pye Limited
(Cambridge, England)
270 Park Ave., New York 17, N. Y.
Amplifiers; amplifier-kit sets; record players; loudspeaker systems.

Racon Electric Co., Inc.
1261 Broadway, New York 1, N. Y.
Loudspeakers.

Radio Corporation of America
Front and Cooper Sts., Camden 2, N. J.
Phonographs; phonograph records; audio components; tape recordings; radios.

The Radio Craftsmen, Inc.
Division of Precision Radiation Instruments, Inc.
4223 W. Jefferson Blvd., Los Angeles 16, Calif.
Tuners; amplifiers; equalizers; filters.

Radio-Electronics
25 W. Broadway, New York 7, N. Y.
Publishers: *Radio-Electronics Magazine;* magazines and books.

Radio Magazines, Inc.
204 Front St., Mineola, L. I., N. Y.
Publishers: *Audio Magazine; First Audio Anthology; Second Audio Anthology; Third Audio Anthology;* books.

Radio Station WQXR
229 W. 43rd St., New York 36, N. Y.
Radio station; AM and FM broadcasts; two-channel stereophonic transmissions.

Radio & Television News
366 Madison Ave., New York 17, N. Y.
Publishers: *Radio and Television News* and *Popular Electronics.*

Rauland-Borg Corporation
3515 W. Addison St., Chicago 18, Ill.
Amplifiers; AM-FM tuners.

Recorded-Tape-of-the-Month Club, Inc.
76 W. 47th St., New York 36, N. Y.
Recorded tape.

Reeves Equipment Corp.
10 E. 52nd St., New York 22, N. Y.
Recording systems.

Reeves Soundcraft Corp.
10 E. 52nd St., New York 22, N. Y.
Magnetic recording materials: quarter-inch tape; oxide-coated motion-picture film.

Rek-O-Kut Company
38-01 Queens Blvd., Long Island City 1, N. Y.
Turntables; disc recorders; recording amplifiers; portable p.a.-phonograph combinations with three-speed arrangements and with continuously-variable speed control; studio consoles; overhead cutting mechanisms.

Revere Camera Company
320 E. 21st St., Chicago 16, Ill.
Tape recorders.

John F. Rider Publisher, Inc.
480 Canal St., New York 13, N. Y.
Publishers: service manuals, books.

Rockbar Corporation
215 E. 37th St., New York 16, N. Y.
Record changers; players; crystal pickups; transcription turntables; automatic record combinations; accessories.

Ronette Acoustical Corp.
135 Front St., New York 5, N. Y.
Phonograph cartridges; pickup arms; microphones.

Sanford Electronics Corp.
157 Chambers St., New York 7, N. Y.
Distributors: audio equipment.

Schober Organ Corporation
35 Dail St., New Hyde Park, L. I., N. Y.
Electronic organs in kit form.

Hermon Hosmer Scott, Inc.
385 Putnam Ave., Cambridge 39, Mass.
Amplifiers; equalizer-preamplifiers; tuners; turntables.

Sherwood Electronics Laboratories, Inc.
2802 W. Cullom Ave., Chicago 18, Ill.
Amplifiers; AM-FM tuners; loudspeaker systems.

Shure Brothers, Inc.
225 W. Huron St., Chicago 10, Ill.
Phonograph cartridges; microphones.

Mark Simpson Manufacturing Co., Inc.
32-28 49th St., Long Island City 3, N. Y.
Tape recorders; amplifiers; tuners; disc recorders; intercommunication systems.

Sonotape, Inc.
166 W. 26th St., New York 1, N. Y.
Pre-recorded tapes.

Sonotone Corp.
P.O. Box 200, Elmsford, N. Y.
Ceramic phonograph cartridges; amplifiers; loudspeakers.

Stan White, Inc.
Division of Eddie Bracken Enterprises
725 S. La Salle St., Chicago 5, Ill.
Loudspeakers and enclosures.

Stephens Manufacturing Corp.
8538 Warner Drive, Culver City, Calif.
Loudspeakers and enclosures; amplifiers; condenser microphones; wireless microphone; multicellular horns; high-frequency drivers; theatre loudspeakers.

Stromberg-Carlson Company
1225 Clifford Ave., Rochester 21, N. Y.
Audio components and completed units in matching cabinets.

Tannoy (Canada) Limited
36 Wellington St. East, Toronto 1, Ontario, Canada
Loudspeakers; enclosures; preamplifiers; amplifiers; pickup cartridges.

Technical Tape Corp.
177th St. and Ft. of Harlem River, Bronx 53, N. Y.
Recording tape and allied products.

Telectrosonic Corp. (Telectro)
35-18 37th St., Long Island City 1, N. Y.
Tape recorders; tape reproducers.

Telefunken
7 Park Ave., New York 16, N. Y.
Radios; record players; microphones; vacuum tubes; audio components; tape recorders.

The Tetrad Company, Inc.
62 Saint Mary St., Yonkers 2, N. Y.
Diamond phonograph styli.

Thorens Company
Atlantic and Stewart Aves., Garden City Park, N. Y.
Record changers; automatic and manual record players; transcription turntables.

Tung-Sol Electric Inc.
95 Eighth Ave., Newark 4, N. J.
Vacuum tubes for audio.

United Audio Products
Division of United Optical Mfg. Corp.
202-4 E. 19th St., New York 3, N. Y.
Loudspeakers; tweeters; woofers; coaxial speakers; record changers.

United Speaker Systems
58 Schuyler St., Belleville 9, N. J.
Loudspeaker systems and enclosures.

United Transformer Co.
150 Varick St., New York 13, N. Y.
Amplifiers; transformers.

University Loudspeakers
80 S. Kensico Ave., White Plains, N. Y.
Loudspeakers; loudspeaker systems; enclosures; loudspeaker components.

V-M Corporation
Fourth and Park Sts., Benton Harbor 1, Mich.
Tape recorders; phonographs; record changers.

Weathers Industries, Inc.
66 E. Gloucester Pike, Barrington, N. J.
Phonograph pickups; loudspeaker assemblies.

Webster-Chicago Corporation (Webcor)
5610 W. Bloomingdale Ave., Chicago, Ill.
Phonographs; tape recorders; radio-phonographs; record changers.

Wendell Plastic Fabrics Corp.
17 W. 17th St., New York 11, N. Y.
Plastic fabrics; grille fabrics.

Westminster Recording Co., Inc.
275 Seventh Ave., New York 1, N. Y.
Phonograph records.

Zenith Radio Corp. of New York
527 W. 34th St., New York 1, N. Y.
Radios; television sets; phonographs; combinations.

Membership Information

New Members

Honorary Members

Everitt, W. L., College of Engineering, University of Illinois, Urbana, Ill.

Terman, F. E., 659 Salvetierra St., Stanford, Calif.

Members

Albin, Clark E., 7002 N. Muscatel Ave., San Gabriel, Calif.

Bidlack, Cecil S., 14 Gregory Hall, Urbana, Ill.

Bounsall, Norman F., 435 Holland Ave., Ottawa, Ont., Canada

Broderick, Thomas A., 565 First St., Brooklyn 15, N. Y.

Burwen, Richard S., 17 Sheffield Rd., Melrose 76, Mass.

Byer, M. T., Byer Industries Pty. Ltd., 8 Dorcas St., South Melbourne, Victoria, Australia

Caporale, Aldo M., 5919 Pulaski Ave., Philadelphia 44, Pa.

Carneal, Robert B., 1622 Abingdon Dr., Alexandria, Va.

Davy, Richard G., 4435 Chevy Chase Dr., La Canada, Calif.

Drake, Frederick H., Old Denville Rd., Boonton, N. J.

Deutsch, Ernest M., 571 Academy St., New York 34, N. Y.

Erath, Louis W., 1811 N. Libbey Dr., Houston 18, Tex.

Etzold, Hellmuth, American Foundation for the Blind, 15 W. 16th St., New York 11, N. Y.

Fischer, Alfred A., 2238 Bailey Ave., Buffalo 11, N. Y.

Fisler, Royal E., 225 Baker Ave., Webster Groves 19, Mo.

Frutchey, M. P., P. O. Box 1028, Winter Park, Fla.

Gammill, Harold L., 2015C Locust St., Long Beach, Calif.

Godai, Takeshi, 32 5-Chome Omiya-Nishinomachi, Asahi-ku, Osaka, Japan

Hollister, David G., 16 Texas Court, Syosset, N. Y.

Hammond, James P., 58 Buntyn St., Memphis, Tenn.

Keith, Clyde R., 22 Argyle Court, Summit, N. J.

Kendall, Osmond K., 97 Vachon St., Ottawa, Ont., Canada

Lanier, R. S., 59 Greenwich Ave., New York 14, N. Y.

Lee, Richard McComas, 348 Fountain Ave., Louisville, Ky.

Mahler, Richard J., 34-41 85th St., Jackson Heights 72, N. Y.

Manfredi, Anthony, 91 Barker Ave., Eatontown, N. J.

McMillan, Ann E., c/o Ruth Leiman, The Hanover Bank, 42nd St. and Madison Ave., New York, N. Y.

Meller, William R., 3452 Harrison St., Denver, Colo.

Moura, Carlos Ellis Ripper de Assis, Pr. da Republica 32, Apt. 801, Sao Paulo, Brazil, South America

Ragland, Robert M., 215 W. 23rd St., New York 11, N. Y.

Rapp, George, Jr., 326 Ridge Ave., State College, Pa.

Reed, Fred A., 4504 S. 3rd Ave., Los Angeles 43, Calif.

Reger, Scott N., Department of Otolaryngology, University Hospital, Iowa City, Iowa

Richards, William J., Billeting Office, White Sands Proving Ground, N. Mex.

Schuler, George L., 7225 Beverly Blvd., Los Angeles 36, Calif.

Shadle, Harry W., 326 Ridge Ave., State College, Pa.

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Deceased Members

It is with sincere regret that the Audio Engineering Society notes the death of two of its members:

Frank M. Figgins, 12220 Hillslope St., Studio City, Calif.
O. K. Garland, WJHL, Inc., Johnson City, Tenn.

Journal Authors

A. I. Aronson

A. I. Aronson received a B.E.E. degree from Syracuse University in 1951. From that time until the present, he has been associated with the RCA Engineering Products Division, Radio Corporation of America, at Camden, New Jersey. His work as a circuit engineer in the General Engineering Development Section has involved audio-amplifier and magnetic-recording circuit development with particular emphasis on transistor applications in the field of audio.

P. D. Collings-Wells

P. D. Collings-Wells studied engineering and communications at Southampton University and received the degree of B.Sc. (engineering) at London University.

He worked as a components design engineer with the E.M.I. Company, ultimately joining Goodmans Industries, Limited of Wembley, Middlesex, England to design and develop commercial and high-fidelity loudspeakers and associated equipment. Mr. Collings-Wells is now Chief of Research for Goodmans Industries, Limited.

A Member of the Audio Engineering Society, Mr. Collings-Wells attended the October, 1955 Convention of the AES and has lectured before a number of sections of the AES in this country.

Homer W. Dudley

Homer Walter Dudley was born in Oranda, Virginia on November 14, 1896. Immediately after receiving the B.S. in E.E. degree from Pennsylvania State College in 1921, he joined the research staff of the Western Electric Company's engineering department (later incorporated as Bell Telephone Laboratories). He received the M.A. degree in Physics from Columbia University in 1924.

Mr. Dudley's research at Bell Laboratories has, in general, related to the improvement of the transmission of speech sound from one person to another by wire, cable and radio-telephone systems. After early work on transmission features of local telephone circuits, he turned to the development of voice-operated circuits for transatlantic radio, long lines, and submarine telephone cable systems. He also worked on research and development problems of coaxial-conductor systems.

In the middle 1930's, he turned to the analysis and synthesis of the spoken word—not from the standpoint of the actual sound waves—but from the standpoint of the nucleus, or inner speech. His work on the design and construction of speech-analyzing and synthesizing circuits led to the development of the Voder, a manual speech synthesizer demonstrated at the New York and San Francisco World Fairs, and the Vocoder, which re-created speech electrically and automatically.

In recent years Mr. Dudley has continued his research on the synthesis of speech, including the development of "visible-speech" equipment to portray the nucleus of speech as a moving picture.

He has been granted 37 patents in the United States and a number abroad for his inventions in the fields of telephony and speech synthesis and is the author of many technical articles on the latter subject.

Mr. Dudley is a Fellow of the Acoustical Society of America, a Senior Member of the Institute of Radio Engineers, and a Member of the Audio Engineering Society. In addition, Mr. Dudley holds membership in the American Institute of Electrical Engineers and the American Association for the Advancement of Science. He is also a member of Eta Kappa Nu, Sigma Tau, and Phi Kappa Phi.

J. Gittleman

J. Gittleman was born in Newark, New Jersey on February 5, 1926. He received the B.S. in E.E. degree at Rutgers University in 1948 and the Ph.D. degree in physics in 1952 at the same school.

He served as an instructor in physics at Rutgers until he joined the staff of the Franklin Institute in 1953 with the title Research Physicist. Dr. Gittleman worked in the field of ferromagnetism at the Franklin Institute and, in particular, studied the properties of single-domain particles. He is now on the staff of the RCA Laboratories at Princeton, New Jersey.

Clyde R. Keith

Clyde R. Keith received the B.S. degree at the California Institute of Technology and the M.A. degree at Columbia University.

Between 1928 and 1949, Mr. Keith engaged in the design, installation and operation of motion-picture sound-recording equipment. During this period he supervised the installation of sound-recording equipment in London, Paris, Rome, and Madrid.

Mr. Keith holds 28 U. S. and foreign patents on sound recording and related subjects.

He is a Fellow and former Editorial Vice-President of the Society of Motion Picture and Television Engineers, a Senior Member of the Institute of Radio Engineers, and a Member of the Audio Engineering Society. Mr. Keith was formerly Chairman of the Sectional Committee on Motion Pictures of the American Standards Association.

Walter O. Stanton

Walter O. Stanton was born in Canton, Ohio in 1914. He studied electrical engineering at Wayne University.

Immediately following college, he joined the Electronic Control Corporation, one of the first companies to apply electronics to the now-widespread field of industrial automation. Continuing to specialize in that field, Mr. Stanton became Vice-President and Chief Field Engineer of the Detroit Univer-

sal Duplicator Company, where he developed and patented an electronic servo system which enabled any standard machine tool to produce complex-contoured machined parts automatically.

Immediately thereafter, and for a period of five years, Mr. Stanton served as Assistant Vice-President in Charge of Engineering with the Control Instrument Company, Inc. (now a Burroughs division), a company specializing in fire-control systems, servo applications and automatic-control devices.

Mr. Stanton became associated with Pickering & Company, Inc. in 1948. He has served that company as Chairman and President since 1950.

The holder of many patents, Mr. Stanton has been responsible for component and systems developments in the fields of automation, fire control, and audio. His work in audio includes the invention and development of the Fluxvalve pickup.

A Member of the Audio Engineering Society, Mr. Stanton is currently serving as Executive Vice-President of the AES for 1955-56.

R. A. VON BEHREN

ROBERT A. VON BEHREN was born in Chicago, Illinois, in 1921. He received the B.S. degree in electrical engineering from Purdue University in 1943.

From 1943 to 1946 Mr. von Behren was employed by the Sperry Gyroscope Company as a field service engineer in airborne radar and navigation aids. He joined the Indiana Steel Products Company in 1946 as a research engineer and was active in the development of magnetic-recording tape and magnetic-recording heads.

Since 1948, Mr. von Behren has been on the staff of the Minnesota Mining and Manufacturing Company, where he has engaged in research and development on magnetic tapes and motion-picture films. Formerly Assistant Technical Director of Minnesota Mining's Magnetic Products Division, he is now that Division's Research and Development Manager.

Mr. von Behren has served on IRE Committee 19 on recording and reproducing standards and on the Standards Committee of the Magnetic Recording Industry Association.

He is a member of Tau Beta Pi and Eta Kappa Nu.

SAUL J. WHITE

SAUL J. WHITE has worked in the audio communications field for 25 years.

He secured his formal education at McGill University.

Between 1929 and 1935 Mr. White was employed by the Western Electric Company as an electrical engineer, then as Senior Development Engineer with the Thomas A. Edison Company. For ten years, ending in 1955, he served as Chief Engineer of University Loudspeakers, Inc., of White Plains, New York. Mr. White is currently Chief Engineer of the Racon Electric Company of New York.

Mr. White has written and lectured on many subjects. At one time or another, he has been concerned with subsonics and ultrasonics, atmospheric turbulence, aviation, speech and hearing, and the military applications of high-intensity sound.

Mr. White's paper, "High-Efficiency, Three-way Speaker System," appeared in the July 1955 issue of the JOURNAL *(3, 155-159).*

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To AES members: Please help the Society grow by passing this blank on to a business associate, co-worker, friend, or acquaintance who works in audio (or is interested in audio) and by acting as his or her sponsor.

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ADMISSION REQUIREMENTS

A MEMBER, according to the constitution, may be any person active in audio engineering who has an academic degree or its equivalent in scientific or professional experience in audio engineering or in a closely related field or art. Such a person shall, upon election, be entitled to all the rights and privileges of the society.

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THE PURPOSE OF THE SOCIETY

The Audio Engineering Society is an organization representing the profession whose field is the recording, transmission, and reproduction of those frequencies audible to the human ear. Its objects are the advancement of the theory and practice of audio engineering and its closely related arts, and the dissemination of important information in this field to its membership. The Society seeks to continue the progress which has been made in audio engineering since the days of the original telephone and continuing through the early microphones, loudspeakers, and amplifying devices. Many of the electronic developments familiar to us today, such as broadcasting, sound motion pictures, and radiotelephony, had their beginnings in audio engineering.

Each year the Society gives the following awards: The Emile Berliner Award for an outstanding development in the field of audio engineering, the John H. Potts Memorial Award to the person who has made an outstanding contribution to the improvement of audio engineering, and the Audio Engineering Society Award to the person whose work has helped most the advancement of the Society in the past year. Honorary Memberships and Fellowships are awarded for past contributions to the profession.

PUBLISHING

Papers presented before conventions or meetings of the Society are often published in the Journal of the Audio Engineering Society, which is sent quarterly, without charge, to all members. Back issues of the Journal are available at reduced member prices. Occasional mailings are also made of news bulletins to members.

MEETINGS AND SECTIONS

The Audio Engineering Society holds conventions in the fall and winter of each year, during which technical papers are presented and exhibits made by manufacturers of equipment used in the audio field. No charge is made to members for admission to the convention. In addition, local sections have been organized in various parts of the country, and abroad, which meet regularly for the presentation of technical papers and discussion of subjects of interest. Those members desiring to learn of sections in their vicinity or to form new sections should correspond with the Secretary.

COMMITTEES

The following committees are now active within the Society: Admissions; Awards; Constitution and By-Laws; Convention; Cooperative Research; Educational Standards; Employment Register; Finance; Historical; Lecture Course; Membership; Nominations; Papers Procurement; Publications; Public Relations; Sections; Standards. Qualified members wishing to serve on any of these committees should address the chairman of the committee involved, giving full details of their relevant experience.

OFFICERS

The Society annually elects a President, Executive Vice-President, Central Vice-President, Western Vice-President, Secretary, and Treasurer for one-year terms, and three members of the six-man Board of Governors for a two-year term.

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A Journal of original record. Papers originally published elsewhere or promised for publication elsewhere are not accepted for presentation at Audio Engineering Society Conventions or for publication in the JOURNAL OF THE AES. In rare instances, exceptions may be made by the Convention and Publications Committees at their discretion.

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Mail that copy of the manuscript which is accompanied by the *reproduction* copies of your illustrative material (the Editor's copy) *flat,* with plenty of stiff cardboard enclosed. It is advisable to mark the envelope "PLEASE DO NOT BEND."

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Time allotment. The average time allowed for any paper, unless the author requests more time on his Author's Form, is 20 minutes. If you are not going to deliver your paper in person, please supply the name of your alternate to the Convention Chairman as early as possible.

Special oral version. An informal version of approximately 20 minutes, having an air of spontaneity, is usually more effective than a rushed verbatim reading of the manuscript exactly as written for publication. Many authors, after submitting the formal full-length version of their paper for publication, prepare an *informal* version for their guidance during oral delivery.

Demonstrations. Demonstrations always add interest. They should be set up well in advance of the particular session for which they are intended and tested under actual operating conditions. The Convention Committee will cooperate in every way within its power.

Facilities. If you expect to need a blackboard or any special facilities (electric power, large table or tables, etc.) please notify the Convention Chairman as early as possible.

Lantern slides. Photographs, diagrams, charts, and curves intended to accompany oral delivery should be in the form of standard American lantern slides (3¼ in. x 4 in.) or 2 in. x 2 in. transparencies. The long dimension of the projected area should be horizontal in the standard slide, but may be either horizontal or vertical in the 2 in. x 2 in. slide.

PLEASE NOTE: Opaque projection of paper prints or drawings is not recommended. Nor can we guarantee that facilities for this type of projection will be provided. Because of the dimness of the image, opaque projection is unsatisfactory for large audiences.

Lettering on lantern slides. Charts, diagrams and curves from which lantern slides are to be made should be held within the proportions or overall dimensions of 7 in. x 10 in., with no more than 20, and preferably only 15 words to a chart. Vertical Gothic capitals are recommended.

For a 7 in. x 10 in. working area, the smallest desirable letter height is 0.14 in. (made with a Leroy pen 0 or Wrico pen 7).

Recommended, too, are the following line widths:

For curves—1½ to 2 points or 0.021 in. to 0.028 in.
For grid rules—½ point or 0.007 in.
For reference lines—1 point or 0.014 in.

Thumb marks. To indicate proper orientation, a thumb mark should be placed in the lower left-hand corner of the slide, when the latter is viewed as it will appear projected on the screen.

More complete information on lantern slide dimensions is given in American Standard Dimensions for Lantern Slides, Z38.7.19-1950.

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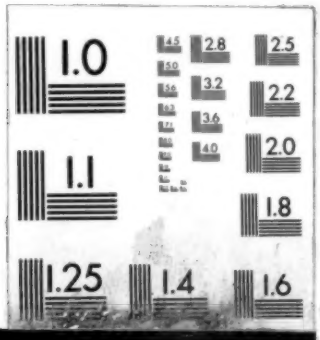
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